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Mars Landing and Reconnaissance Mission Environmental Control and Life Support System Study

Volume 1
Study Summary and Conclusions

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

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FOREWORD

This is Volume One of the final report of the "Mars Landing and Reconnaissance Mission Environmental Control and Life Support System Study." This study was conducted by Hamilton Standard under contract NAS 9-1701 for the Manned Spacecraft Center of the National Aeronautics and Space Administration. The study, conducted from July 15, 1963 to March 15, 1964, was directed by Mr. K. L. Hower, and the principal contributors were Messrs. V. J. Binks, R. L. Brown, R. Lamparter, M. R. Segal, J. F. Wilber, and J. Warner.

Acknowledgement is made to all the industrial organizations mentioned in the report whose assistance in their special areas provided the information necessary for the study to present valid results. Special thanks are due Messrs. W. W. Guy, M. R. Reumont, and J. T. Brown of the Systems Analysis Section, Environmental Control Systems Branch of the Crew Systems Division, Manned Spacecraft Center for their advice and guidance.

The total report is contained in three Volumes as listed below:

Volume 1	Study Summary and Conclusions
Volume 2	Subsystem Study Results
Volume 3	System Study Results

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1.0 INTRODUCTION

This volume of the final report presents a review of the entire study including the major conclusions reached and a description of the subsystems and systems considered. It is intended as a summary volume to provide a comprehensive review of the work done without the full details and substantiating data. This volume includes a summary of the subsystem studies with brief descriptions of the subsystem approaches considered as well as the principal conclusions; descriptions of the integrated systems devised for each module of the Mars spacecraft; and a comprehensive discussion of the conclusions and recommendations of the study.

The final working specifications for the study is discussed in Section 3.0 of this volume to provide familiarity with the intent of the study. Section 4.0 illustrates the study methodology utilized by Hamilton Standard in performing the study, and should serve as a basis for understanding the format of the rest of the report.

Considerable detail is devoted to the results of the subsystems studies to familiarize the reader with the basic subsystem concepts as well as the advantages and disadvantages of each for this particular mission requirement. The sections devoted to final system descriptions present summary discussions of each of the systems to illustrate the arrangement of components, the performance characteristics, and the weight requirements. Full detailed reporting of the subsystem and system areas is presented in Volumes 2 and 3 of this report, respectively. The trade-off studies and detailed performance criteria are included in these volumes.

Section 2.0 of this volume presents the major conclusions and recommendations.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 General

The object of this study was to determine the detailed requirements of the Environmental Control and Life Support System (ECLSS) necessary to support the crew on a landing and reconnaissance mission to the planet Mars. These requirements were then used to evaluate the presently known methods of performing each of the functions over the range of interest, presenting this information so that comparisons can be made for any specific point of interest within this range. The study then selected the best of each of these subsystems and combined them to form an integrated ECLS system for the particular mission presently being considered.

The most important characteristics of the various subsystems evaluated and those used to compare these subsystems are:

1) Total Equivalent Weight
   Fixed Weight
   Expendable Weight
   Weight Equivalent of Power Required; Evaluated at:
   a) 500 lb/kw for the Mars Mission Module
   b) 150 lb/kw + 1.5 lb/kwh for the Mars Excursion and Earth Reentry Modules
2) Simplicity of Construction and Operation
3) Growth Potential for Longer Missions
4) Crew Comfort and Safety

The principal guidelines for this particular mission are summarized below:

1) Launch Date:	1973
2) Mission Duration:	
a) Earth to Mars	120 days
b) Mars Stay	40 days
c) Return to Earth	260 days
Total Mission	420 days

3) Crew: 6 men
4) Power Supply: Nuclear Reactor on Main Vehicle; fuel cells on Mars Excursion and Earth Reentry Modules.
5) Cabin Pressure: 7.0 psia nominal; 50/50 mixture of O_2/N_2.

The presently envisioned spacecraft consists of three modules: the Mission Module, the Excursion Module, and the Earth Reentry Module. The design mission specifies that the crew of six will travel from Earth to Earth orbit in a ferry vehicle (possibly a modified Apollo) or the Earth Reentry Module. After transfer to the Mission

2.1 (Continued)

Module, they will travel from Earth orbit to Mars orbit in the Mission Module. Three of the crewmen will then descend to the Mars surface in the Excursion Module and return at the end of 40 days. The six crewmen will return to Earth vicinity in the Mission Module, then transfer to the Earth Reentry Module to re-enter the atmosphere and land back on Earth.

The weight and power of the EC/LS systems defined by this study for each of the three modules are shown in Table 2-1.

TABLE 2-1

	MMM	MEM	ERM
Dry Weight plus Fluid and Expendables - Lbs.	4463.2	1783.5	1197.2
Average Power - Watts	1562.0	608.2	393.0
Equivalent Weight of Power - Lbs.	782.2	1030.1	623.0
Total Equivalent Weight - Lbs.	5245.4	2813.6	1820.2

2.2 Conclusions

Space missions of long durations require radical departures in two aspects from the current short duration missions such as Mercury, Gemini, and Apollo. The first aspect is in the area of reliability and maintenance, and the second is the concepts which are required to perform certain of the life support functions.

System reliability in short duration missions can be achieved by a conservative design philosophy and by inclusion of redundant items for the critical functions. These methods are still valid for long duration missions, but a third method must be included to achieve the desired reliability; that is, inflight maintenance by the crew. In order to achieve this, it is necessary that the systems be designed to be accessible and repairable as installed in the vehicle.

The need for new concepts in certain areas of life support can best be illustrated by considering some of the present concepts and their application to a Mars mission. The first area is that of oxygen supply. Present spacecraft supply oxygen to the crew completely from storage vessels rather than reclaiming a portion of the oxygen

2.2 (Continued)

required by reducing the exhaled CO_2 to carbon and oxygen. If this were done for the Mars mission it would require nearly 5000 pounds of oxygen. Reclamation equipment to recover this O_2 from the CO_2 has a total equivalent weight of about 800 pounds. Another example is carbon dioxide removal. If done by the expendable lithium hydroxide as in present spacecraft, about 6200 pounds of LiOH would be required. This same function can be accomplished for a total equivalent weight of about 250 pounds by using a regenerable adsorbent. Water is used as a heat sink in present spacecraft. For the Mars mission this would require over 300,000 pounds of water to be carried compared to the 100 pound weight of a space radiator. In addition, the crew would require about 50,000 pounds of water for personal use while the total equivalent weight of equipment to reclaim water from urine and wash water is only 350 pounds.

Table 2-2 shows the method selected to perform each function of the ECLS system for each module. The equipment selected represents various stages of development but in each of the cases listed industry has at least demonstrated the laboratory feasibility of the approach by test.

Thus, this study indicated that, from an EC/LSS aspect, there are no major breakthroughs or new concepts required to make the manned exploration of Mars possible in 1973 or later. However, although the concepts exist, several of these approaches require significant advanced research, design and development work before the mission can be attempted. This work can probably be accomplished on a "crash" basis in about 3 to 4 years, or on a more reasonable basis in 7 to 8 years. Much of this research and development work which is required prior to interplanetary missions is also required prior to the long term Earth orbiting space stations missions. Regardless of the time sequencing of these missions, any work done will benefit both programs. Therefore, it is recommended that this work be started in the near future so it can be done on a carefully planned and efficient basis. The two areas which are most critically in need of advanced design and development work are reduction of carbon dioxide for reclamation of oxygen, and subcritical cryogenic storage of oxygen and nitrogen. Specific areas for additional work are pointed out in the following section.

This study considered 1973 as the tentative mission date. Based on what is known today, the conclusions drawn here are not anticipated to change if the mission were planned for some later date. While it is possible that concepts still to be discovered at some time in the future may permit improved approaches and result in better, lighter and/or more reliable equipment, the date of 1973 need not be the limiting factor of any concept considered in this study.

MAJOR FUNCTION	MARS MISSION MODULE			
	RECOMMENDED APPROACH	*ALTERNATE APPROACH	COMMENTS	RECOMMENDED APPROACH
AIR CIRCULATION	ELECTRICALLY DRIVEN FANS	NONE	CURRENT STATE OF THE ART (S.O.T.A.) NO PRE-PROGRAM DEVELOPMENT REQUIRED.	ELECTRICALLY DRIVEN FANS
HUMIDITY CONTROL	CONDENSATION FOLLOWED BY A TURBINE DRIVEN ROTARY WATER SEPARATOR.	NONE	CURRENT STATE OF THE ART TECHNOLOGY APPLICABLE NEW SIZE REQUIRED.	CONDENSATION FOLLOWED BY ELECTRICALLY DRIVEN ROTARY WATER SEPARATOR.
CONTAMINANT CONTROL	A. CHARCOAL REMOVES ODORS, ETC. B. FILTERS REMOVES DUST, ETC. C. CATALYTIC BURNER OXIDIZES CRITICAL CONTAMINANTS TO OTHERS (H_2O, CO_2, ETC.) WHICH MAY BE REMOVED BY OTHER VEHICLE SUB-SYSTEMS D. CHEMI-SORBENT BED USED TO PROTECT THE CATALYTIC BURNER FROM CONTAMINANTS WHICH WON'T OXIDIZE OR WHICH OXIDIZE INTO MORE HARMFUL CONTAMINANTS.	A. NONE B. NONE C. NONE D. NONE	THE PRIMARY UNKNOWN IN THIS AREA IS THE CONTAMINANT TYPES, ALLOWABLE CONCENTRATION, AND CONTAMINANT PRODUCTION RATES TO BE EXPECTED FROM ALL OF THE EQUIPMENT IN THE SPACECRAFT. ONLY METABOLIC CONTAMINANTS ARE CURRENTLY WELL DEFINED. THIS DEFINITION OF THESE REQUIREMENTS WILL HAVE A DIRECT BEARING ON THE SIZE, POWER, AND EXPENDABLE REQUIREMENTS OF THE CONTAMINANT CONTROL SUB-SYSTEM.	SAME AS MISSION MODULE.
CARBON DIOXIDE REMOVAL	REGENERABLE SOLID ADSORPTION SYSTEM REMOVES CO2 BY PHYSICAL ADSORPTION IN A CHEMICAL BED. THE BED IS REGENERATED BY HEAT	MOLTEN CARBONATE	THE SOLID ADSORPTION SYSTEM IS WELL DEVELOPED AND LIGHT IN WEIGHT. IT INTEGRATES WELL WITH ALL REDUCTION SYSTEMS. PERFORMANCE OF ADSORBENTS UNDER HEATED DESORPTION REQUIRES ADDITIONAL TESTING PRIOR TO FINAL UNIT SIZING. MOLTEN CARBONATE, IF USED AS REDUCER OF CO_2 TO O_2 AND CARBON, ALSO REMOVES CO_2 FROM ATMOSPHERE. MOLTEN CARBONATE NOT AS WELL DEVELOPED AS SOLID ADSORPTION.	CRYOGENIC FREEZE OUT.
CARBON DIOXIDE REDUCTION	SOLID ELECTROLYTE – CO_2 ELECTROLYZED ACROSS A SOLID ELECTROLYTE TUBE TO PRODUCE O_2, CARBON DEPOSITED ON IRON CATALYST MESH. MOLTEN CARBONATE – A MOLTEN CARBONATE BATH REMOVES CO_2 FROM THE PROCESS AIR (ELIMINATING THE NEED FOR A SEPARATE CO_2 REMOVAL SYSTEM) AND ELECTROLYTICALLY DISSOCIATES IT INTO OXYGEN AND CARBON (PLATED ON THE CATHODE) SOLID ELECTROLYTE HAS SLIGHTLY BETTER DEVELOPMENT STATUS THAN MOLTEN CARBONATE, BUT MOLTEN CARBONATE IS LIGHTER IN WEIGHT FOR MARS MISSION AND HAS POTENTIAL OF EVEN GREATER WEIGHT SAVINGS WITH INCREASED MISSION TIME. PARALLEL DEVELOPMENT OF BOTH IS RECOMMENDED WITH PERIODIC TRADEOFF STUDIES TO DETERMINE FUTURE COURSE OF DEVELOPMENT BASED ON RESULTS TO DATE.			NONE REQUIRED
ATMOSPHERIC STORAGE	SUBCRITICAL STORAGE	SUPERCRITICAL STORAGE	SUBCRITICAL STORAGE LIGHTER BUT NOT WELL DEVELOPED. SUPERCRITICAL STORAGE GOOD BACKUP SYSTEM IF REQUIRED DUE TO DEVELOPMENT PROBLEMS.	SUBCRITICAL STORAGE
WATER RECLAMATION	AIR EVAPORATION SYSTEM WASTE WATER IS PRETREATED AND FED TO A WICK EVAPORATOR WHERE THE WATER IS EVAPORATED INTO A CIRCULATING AIR STEAM. RECOVERY IS BY CONDENSATION AND SEPARATION. CONTAMINANTS ARE LEFT IN THE WICKS.	NONE	THE AIR EVAPORATION SYSTEM USES CURRENT STATE-OF-THE-ART EQUIPMENT. NO SIGNIFICANT PRE-PROGRAM DEVELOPMENT PROBLEM EXISTS. POSSIBLE ADVANTAGE TO BE GAINED BY DEVELOPING WICK REGENERATION TECHNIQUE.	NONE REQUIRED
WASTE MANAGEMENT	GERMICIDE TREATMENT AND STORAGE.	DISTILLATION AND PYROLYSIS TO RECOVER WATER.	GERMICIDE AND STORAGE ADQUATE FOR SAFETY. DUE TO LENGTH OF MISSION IT IS POSSIBLE TO RECOVER OVER 800 POUNDS OF WATER BY USE OF A 200 POUND DISTILLATION AND PYROLYSIS UNIT. IF GROUND RULES PERMIT USE OF FECAL WATER THIS SYSTEM SHOULD BE CONSIDERED.	GERMICIDE TREATMENT AND STORAGE.
THERMAL CONTROL	SPACE RADIATOR WITH HEAT TRANSPORT LOOP CONTAINING FC-75.	NONE	CURRENT STATE OF THE ART. FC-75 SELECTED FOR LOW PUMPING POWER AND WIDE TEMPERATURE RANGE.	SPACE RADIATOR WITH FC-75 HEAT TRANSPORT LOOP. ISOTOPE HEAT SOURCE AND PASSIVE RADIATOR PANEL.

#1

TABLE 2-2

ARS EC/LSS SUMMARY

MARS EXCURSION MODULE		EARTH REENTRY MODULE		
*ALTERNATE APPROACH	COMMENTS	RECOMMENDED APPROACH	*ALTERNATE APPROACH	COMMENTS
NONE	CURRENT S.O.T.A.	ELECTRICALLY DRIVEN FANS.	NONE.	CURRENT S.O.T.A.
NONE	CURRENT S.O.T.A. REQUIRES NEW SIZING AND ADAPTING TO ELECTRIC MOTOR DRIVE.	CONDENSATION FOLLOWED BY AN ELECTRICALLY DRIVEN ROTARY WATER SEPARATOR.	NONE.	CURRENT S.O.T.A. REQUIRES NEW SIZING AND ADAPTING TO ELECTRIC MOTOR DRIVE.
NONE	SAME AS MISSION MODULE.	SAME AS MISSION MODULE.	NONE.	SAME AS MISSION MODULE.
REGENERABLE SOLID ADSORPTION.	CRYOGENIC FREEZE-OUT IS LIGHTER THAN RE-GENERABLE SOLID ADSORPTION BUT NOT AS WELL DEVELOPED. CRYOGENIC FREEZE-OUT ALSO USABLE ONLY IN SYSTEMS WITH FUEL CELL WHERE LARGE AMOUNTS OF CRYOGENIC FLUID AVAILABLE FOR COOLING. MAY NOT BE POSSIBLE TO DEVELOP SYSTEM FOR SUCH LIMITED USE AND GROWTH POTENTIAL. REGENERABLE SOLID ADSORPTION GOOD ALTERNATE.	LITHIUM HYDROXIDE.	NONE.	MISSION TOO SHORT TO WARRANT ANY APPROACH OTHER THEN CHEMICAL ABSORBENT I.E. LiOH.
NONE	MISSION TOO SHORT AND POWER PENALTY TOO HIGH TO WARRANT REDUCTION. LIGHTER TO CARRY CRYOGENIC O_2.	NONE REQUIRED.	NONE.	SHORT MISSION DOES NOT NEED RECLAMATION OF O_2 FROM CO_2.
SUPERCRITICAL STORAGE.	SAME AS MISSION MODULE.		NONE.	GASEOUS STORAGE ONLY SLIGHTLY HEAVIER THAN CRYOGENIC STORAGE. GASEOUS MUCH SIMPLER.
NONE	SUFFICIENT WATER PRODUCED BY FUEL CELL.	NONE REQUIRED.	NONE.	SUFFICIENT WATER CAN BE OBTAINED FROM MISSION MODULE JUST PRIOR TO SEPARATION.
NONE	PRIME INTEREST IS SAFE STORAGE SINCE WATER IS NOT REQUIRED. GERMICIDE AND STORAGE CONTAINERS ARE PRESENT STATE OF THE ART.	GERMICIDE TREATMENT AND STORAGE.	NONE.	SAME AS MARS EXCURSION MODULE.
CONVECTORS WITH THERMAL STORAGE. ABSORPTION REFRIGERATION.	PRESENT KNOWLEDGE OF MARS ATMOSPHERE INDICATES THAT RADIATORS ARE SATISFACTORY. HOWEVER, SOME ESTIMATES OF ATMOSPHERIC COMPOSITION INDICATE ATMOSPHERE IS NOT TRANSPARENT TO INFRARED. IF THIS IS SO, OTHER METHODS OF HEAT REJECTION USING THE ATMOSPHERE OR THE MARS SURFACE AS HEAT SINKS MAY HAVE TO BE USED.	SPACE RADIATOR DURING PRE-REENTRY PHASE. WATER BOILER DURING MAIN PART OF RE-ENTRY PHASE. FREON BOILER DURING LATER PART OF REENTRY PHASE AND POST REENTRY.	NONE.	ALL THREE SYSTEMS ARE CURRENT STATE OF THE ART.

* APPROACHES WITH ENOUGH MERIT TO WARRANT FURTHER INVESTIGATION PRIOR TO FINAL SYSTEM SELECTION.

2

2.3 Recommendations

Many problem areas have been found where it is necessary to start advanced development in the near future if the Mars mission is to be achieved in 1973. These areas should also be considered for advanced development in an Earth orbit space station prior to attempting a Mars mission.

These requirements are presented here according to EC/LSS function.

2.3.1 Carbon Dioxide Removal and Transfer

The two most promising methods of CO_2 removal from the atmosphere and concentration and transfer to a reduction unit are by means of a regenerable solid adsorbent or a regenerable liquid absorbent. The solid adsorption system has had extensive development as a removal system when the material is desorbed to vacuum and the CO_2 discharged overboard. Advanced development of a system to concentrate and transfer the CO_2 is currently underway. However, further optimization and development is required relating the system performance to desorption temperature so the CO_2 can be delivered at the desired purity and at positive pressure to the reduction unit. While the liquid absorption method has been used extensively in submarines, very little experimental work has been done toward adapting the system to flight weight, zero gravity type hardware. The major unknown in this system is the CO_2-liquid contactor, which requires feasibility testing and experimental demonstration.

2.3.2 Carbon Dioxide Reduction

Carbon dioxide reduction to reclaim O_2 from the CO_2 is an absolute necessity for long duration missions such as the Mars mission. The three most promising methods are hydrogenation (Bosch), electrolysis of CO_2 across a solid electrolyte, and electrolysis of molten carbonate. The Bosch is currently the most highly developed of these three but is several hundred pounds heavier than the solid electrolyte or the molten carbonate. The molten carbonate process currently requires the addition of chemicals to the melt periodically to replenish that lost by entrainment in the discarded carbon removed from the CO_2. A laboratory breadboard system has demonstrated the ability to separate this carbon without any melt entrainment. If this process can be developed to be continuous or semi-continuous (large batches) in a space flight configuration, the expendable chemicals will no longer be required and the weight savings of molten carbonate will increase with increasing mission time. Therefore, it is recommended that the following development work be undertaken:

1) Molten Carbonate
   a) Experimental work on improving carbonate density and removal techniques.
   b) Convert present laboratory concept into a flight prototype design.

2.3.2 (Continued)

2) Solid Electrolyte
   a) Perform electrode studies to increase useful life of electrodes.
   b) Study catalytic reactor design in attempt to increase carbon to catalyst ratio.
   c) Convert present laboratory concept into a flight prototype design.
3) Conduct extenisve advanced development and experimental flight evaluations of the most promising approach when research has been carried far enough to permit a valid selection.

2.3.3 Atmospheric Storage

The study of oxygen and nitrogen for atmospheric replenishment has indicated that these fluids may be stored subcritically. Subcritical storage results in lighter tankage than supercritical storage by more than 200 pounds for the Mars Mission Module. However, the development status of subcritical storage is far behind that of gaseous and supercritical storage. Therefore, it is recommended that additional development work be conducted in this area including zero "g" evaluation. The principal problem of subcritical storage is the difficulty in expelling and metering the fluid which may be all liquid, all gas, or a mixture of both. Further, because oxygen stored subcritically is held at 100 psia or lower, gaseous storage vessels for portable life support systems can not be filled directly from this source. The volume penalty for gaseous storage vessels at 100 psia would be excessive. Therefore, it is necessary to develop a converter to receive low pressre subcritical fluid and deliver high pressure (1000-2000 psia) gas.

2.3.4 Water Reclamation

The most promising approaches for reclaiming water from urine and wash water are air evaporation, electrodialysis and vapor compression. Each of these is presently being operated in "breadboard" and early prototype form, but there are still some problem areas requiring additional work. Therefore, it is recommended that the following work be done:

1) Air Evaporation
   a) Develop methods of regenerating the wicks
   b) Develop open loop operation with particular attention to possible contaminant problems.
   c) Build a flight prototype unit and evaluate in ground and flight tests.
2) Electrodialysis
   a) Develop means of increasing membrane life.
   b) Research means of regenerating charcoal.

2.3.4 (Continued)

3) Vapor Compression
   a) Develop means of effectively removing scale from the evaporator.
   b) Improve start cycle to make unit more acceptable to part time operation.

In addition to the above, more work is needed to develop better detergents and methods for removing these detergents after use. Some research has been done on ionic resins which have an affinity for detergents, and are capable of removing many times their own weight of detergent. If these are developed, it will result in lighter weight wash water purification systems.

2.3.5 Personal Hygiene

The major hygiene area which requires further work is that of waste collection devices. A conventional toilet seat with a vectored air blast has been selected for feces collection on the Mars Mission Module. However, none of the available methods of urine or feces collection are very satisfactory considering convenience to the user and simplicity of construction and operation. Therefore, more work should be done toward developing more satisfactory collection devices.

2.3.6 Contaminant Control

The study has pointed out that there are readily available methods for controlling the various contaminants expected in the Mars spacecraft. However, many of these contaminants are generated by the materials used in the craft. The generation rates of many of these contaminants are not known. Therefore, the contaminant control equipment can not be properly sized. It is recommended that the contaminant generation rates of the materials expected be investigated under normal and emergency conditions to evaluate both steady and transient contaminant control requirements. It is also recommended that more study and experimental work be done to firmly establish maximum acceptable concentrations of each contaminant for extended flights.

2.3.7 Mars Surface Conditions

A major problem during the Mars exploration is the thermal control of the Excursion Module. The characteristics of the Mars model atmosphere as used for this study are such that water evaporation can not be used as a heat sink and the operation of a space radiator is somewhat open to question. Therefore, it is recommended that future studies and probes of Mars include a determination of:

2.3.7 (Continued)

a) Atmospheric pressure
b) Atmospheric composition
c) Radiation transparency of the atmosphere
d) Radiation characteristics of the Martian surface

3.0 SPECIFICATION REVIEW

This section is intended to briefly illustrate the major operating ground rules that the study and final system selections were based on. Since any system result is quite dependent upon the initial criteria established. a review of the specification outline is advisable to provide common understanding of the study results and the selection criteria for the various equipment.

The specification is presented in outline form to allow rapid reference to the major groupings of parameters. The basic specification provided by the NASA has been expanded during the study to provide the overall depth required for the final system integration. A series of discussions with the personnel in the Systems Analysis Section of the NASA/Manned Spacecraft Center resulted in this final specification.

MARS STUDY SPECIFICATION

3.0 (Continued)

ITEM	DESCRIPTION
Vehicle Configuration	Three module vehicle - An Earth Re-entry Module (ERM) which will transfer the crew from Earth to the orbiting ship and return the crew to Earth at the end of the mission. A Mars Mission Module (MMM) which will carry the crew to Mars orbit and return them to Earth orbit. A Mars Excursion Module (MEM) which land men on Mars for exploration and return them to the Mission Module which is in Mars orbit.
Flight Plan	a. Launch ERM into Earth orbit to join with balance of ship in 12 hours. b. Transit to Mars in MMM about 120 days. c. MEM descent in 30 minutes. d. Mars stay time - 10 to 40 days. e. MEM return to MMM in 55 hours maximum. f. Transit from Mars to Earth in MMM about 260 days. g. Return to Earth in ERM about 3 days including vehicle checkout.
Launch Date	About 1973
Crew Size	(see below)

Crew Size:

	PRIMARY MISSION	ALTERNATE "PICK-UP" MISSION
a. ERM		
Launch	6 men	4 men
Re-entry	6 men	6 men*
b. MMM		
Outbound	6 men	4 men
Mars Orbit	3 men	2 men
Return	6 men	6 men*
c. MEM		
Mars Entry	3 men	2 men
Mars Stay		
Maximum	3 men	4 men*
Minimum	2 men	1 man
Mars Launch	3 men	4 men*

* Pick-up of two men sent to Mars on a previous one-way mission. Four men in MEM for 55 hours during ascent and rendezvous only.

MARS STUDY SPECIFICATION

3.0 (Continued)

ITEM	DESCRIPTION
Vehicle Orientation	Vehicle will be sun oriented.
Metabolic Data	(see table below)
Wash Water	a. ERM - 0 b. MMM - 12-40 lb/man-day c. MEM - 12-40 lb/man-day Note: Wash contaminants based on the NASA Life Sciences Data Book.
Cabin Pressure (All Modules)	Total Pressure - 7.0 psia Oxygen Partial Pressure - 3.5 psia

Metabolic Data:

	Units	MMM	ERM and MEM	Extra-vehicular
1. Oxygen Intake	lb/man-day	1.84	2.21	3.6
2. Carbon Dioxide Output	lb/man-day	2.12	2.5	4.32
3. Total Heat Output	BTU/man-day	11,200	14,400	22,320
a) Latent Heat				
1) Respiration	BTU/man-day	2,800	4,800	5,520
2) Perspiration	BTU/man-day	0-700	0-700	12,840-13,140
b) Sensible Heat	BTU/man-day	8,400	9,600	3,960
4. Water Balance				
a) Intake				
1) Food & Drink	gms/man-day	2,800	3,600	9,120
2) Water of Oxidation	gms/man-day	350	350	350
b) Output				
1) Urine	gms/man-day	1,500	1,515	1,200
2) Respiration	gms/man-day	1,300	2,085	2,400
3) Perspiration	gms/man-day	0-300	0-300	5520-5820
4) Fecal Water	gms/man-day	50-350	50-350	50-350

Note: The study ground rules do not permit the water created by oxidation of food to be used to achieve a water balance by reuse by the crew.

MARS STUDY SPECIFICATION

3.0 (Continued)

ITEM	DESCRIPTION
Free Air Volume	a. ERM - 320 ft^3 b. MMM - 3000 ft^3 to 3500 ft^3 c. MEM - 1000 ft^3
Relative Humidity	35 to 70% (Controllable within this range if possible)
CO_2 Limits	Normal - 5.0 mm Hg max. (design point) Maximum - 7.6 mm Hg max. (short duration peaks) Emergency - 15.0 mm Hg max. (allowable during emergencies only)
Temperature	65 to 75°F design point
Thermal Loads (Watts)	see table below
Airlock Operations	A trade-off study was made comparing vacuum pumps with stored supplies. The airlock on the mission module will be operated 25 times and the airlock on the excursion module will operate 100 times.
Power Supply	see table below

Thermal Loads (Watts):

	ERM	MMM	MEM
Communication	500	2,900	1,345
ECS	300 *	4,600 *	290 *
Instrumentation	240	830	565
Control and Guidance	200	500	800
Scientific	--	300	300
Subtotal	1,240	9,130	3,300
20% Contingency	248	1,826	660
Total	1,488	10,956	3,960

* These loads were assumed for initial equipment sizing only. Results of the study show ERM = 393 watts, MMM = 1562 to 2025 watts, and MEM = 608.2 watts.

Power Supply:

	Vehicle	Type	Penalty
a.	ERM	APU	150 lb/KW + 1.5 lb/KWH
b.	MMM	Nuclear and/or Solar	300-500 lb/KW
c.	MEM	Fuel Cell	150 lb/KW + 1.5 lb/KWH

MARS STUDY SPECIFICATION

3.0 (Continued)

ITEM	DESCRIPTION
Air Circulation	Sufficient flow was used to provide heat rejection at a temperature level adequate for crew comfort.
Areas of Study	Specifically, requirements were established for the environmental control and life support systems which include the following subsystems and functional areas: 1. Atmospheric Supply a. Storage b. Reclamation 2. Atmospheric Conditioning a. Circulation, humidity control, particulate removal b. Carbon dioxide control c. Contaminant control 3. Thermal Control a. Radiation to space b. Evaporative cooling c. Convective cooling to Mars atmosphere 4. Controls and Instrumentation a. Cabin pressure b. Oxygen partial pressure c. Carbon dioxide partial pressure d. Temperature e. Humidity f. Atmospheric composition analyzer g. Potability of water 5. Water Management a. Waste water collection and reclamation b. Water dissociation (to reclaim oxygen) c. Atmospheric water collection

MARS STUDY SPECIFICATION

3.0 (Continued)

ITEM	DESCRIPTION
Areas of Study (Continued)	6. Waste Management (Solid) a. Storage b. Disposal c. Reclamation 7. Pressure Suit Integration a. Complete integration with the vehicle ECS b. Partial integration with the vehicle ECS c. Independent systems 8. Personal Hygiene a. Wet bath b. Impregnated cloths c. Oral hygiene d. Shaving e. Barbering 9. Maintenance a. Spares b. Commonality of components c. Commonality of functions d. Scheduled maintenance shutdowns
Vehicle Leakage	a. ERM .2 lb/hr b. MMM .1 lb/hr c. MEM .2 lb/hr
Electronics Cooling	Normal temperature 120°F Maximum temperature 160°F Percentage liquid cooled 90%

MARS STUDY SPECIFICATION

3.0 (Continued)

ITEM	DESCRIPTION
Repressurizations	a. ERM 1 b. MMM 3 c. MEM 1
Contaminant Production Rates	Estimated from literature. These rates are presented in Section 11.0, Volume 2 of this report.
Space Cleanliness Requirements	Any gases may be dumped to space (i.e. feces desorption, charcoal regeneration). Solids should not be dumped.
Portable Life Support System (PLSS) Mission Schedule	a. ERM 6 charges b. MMM 12 charges c. MEM 80 charges Each charge shall support one man for 4 hours
Access Door Dimensions	A maximum diameter of 36" for equipment was used as a guideline.
Wall Heat Leakages	Determined by HSD from vehicle drawings. Average heat leak for each module was assumed to be zero.
Radiator Area	One half of the vehicle skin was used with the tube configuration based on weight optimization including meteoroid protection.

MARS STUDY SPECIFICATION

3.0 (Continued)

ITEM	DESCRIPTION
Gravity Environment	All components must operate with zero gravity as well as gravity fields up to 1 "g".
Waste Heat Source (MMM Only)	Total available: 30 to 50 KW Temperature levels: 1470° to 2190°F (thermionic); 600° to 900°F (nuclear) Heat transfer fluid: Liquid metal or Dowtherm
Emergencies	The nature of the mission is such that each ECS of the three modules (MMM, MEM and ERM) must provide for failures without relying on another module. Once committed to the MARS mission the vehicle cannot be turned around for abort in the event of a failure. Spare parts and redundancy was, therefore, used throughout the design of each systems wherever a failed item would be critical to the operation of the vehicle or the safety of the crew.
Food Supply	To provide a basis for the water balance, it was assumed that dehydrated food would be used. Water required for reconstituting this food was then included in the water use rate. Food and feeding was not otherwise considered in the study.

4.0 STUDY METHODOLOGY

4.1 General

This section defines the methodology utilized in performing this study for the Manned Spacecraft Center. A review of the overall procedure will aid understanding of the presentation of the data. A study flow chart has been prepared to present the major relationship of study functions and is illustrated in Figure 4-1. The text elaborates on this flow chart.

4.2 Study Specification

For this study, a primary requisite was the establishment of a good comprehensive study specification. At this phase of the study, definition of the performance requirements for design and off-design conditions of the system were made. The general ground-rules for items such as emergency reserves, suit operation, radiator repairs, etc. were established at this point. Selection criteria and mission requirements for end system were also determined.

4.3 Subsystem Functions

At this phase in the study, an investigation of industry state-of-the-art was required to determine applicable subsystems and components for consideration in the system integration phase. Known equipment data and performance requirements were collected and analyzed. Weight and operational characteristics were also determined.

4.4 Feasibility and Availability Considerations

At this point in the study, the test results and practicality of each subsystem were considered. Any impractical subsystems were rejected.

4.5 Subsystem and Component Evaluation

At this point the available data were reduced to weight, power, and expendable requirements. Specification requirements and environmental conditions were evaluated, and the performance data were prepared so as to be most useful to the systems integration phase of the study.

4.6 Thermodynamic Compatibility Study

Flow, temperature, and heat load mating of heat sources and heat sinks was determined. Water balances were made if required on applicable subsystems. Systems which did not meet this criteria were rejected at this time if the heat loads were greatly mismatched.

STUDY PROCEDURES FLOW CHART

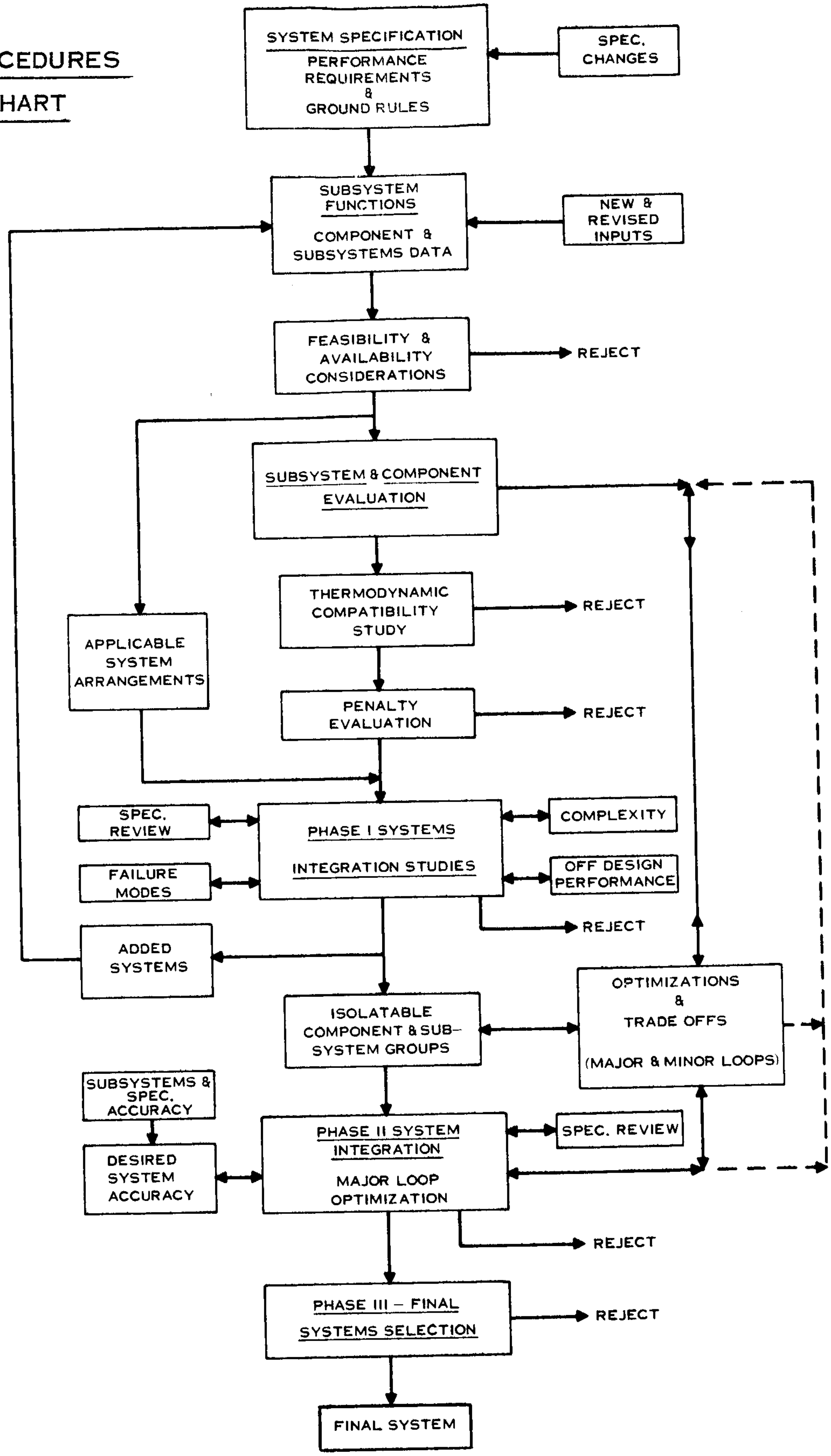


FIGURE 4 – 1

4.7 Penalty Evaluation

Weight and power consumption were considered at this point in the study. Subsystem concepts were rejected if similar, more optimum subsystems or components were available. Final consideration of availability and other selection criteria were included to determine the first step candidate approaches for the final system.

4.8 Applicable System Arrangements

During the overall subsystem evaluation period, subsystem arrangements were considered to determine final suitability of the subsystem to the final system integration. Items such as air distribution systems, arrangement of the liquid loop, etc. were considered in a preliminary fashion.

4.9 Phase I Systems Integration

After collection and evaluation of the subsystem data, the Phase I systems integration was performed. This phase was a rough integration approach combining available components and subsystems in applicable schematics. Failure mode, system complexity and off-design considerations were made here to further reject any subsystem considerations which did not meet overall system integration requirements.

4.10 Added Systems

During the Phase I system integration study, additional requirements often resulted which required evaluation of new subsystems. Any additional studies required by this step went through the same procedure as the other subsystems, starting at the subsystem function phase.

4.11 Isolatable Components and Subsystem Groups

This step selected components and subsystems which have interfaces which must be justified or optimized. It was often necessary to make certain assumptions to permit trade-offs to be carried out efficiently. An assumption of this type is zero weight ducting in an air loop optimization if the duct weight is insignificant compared to the pumping power requirements.

Optimizations and trade-offs were then performed using available data as generated in the subsystem and component evaluations. Component integration information was then fed back to the evaluation section for reprocessing, since it may have affected overall system performance (i.e., the assumption of isolatability may not have been valid). This idea of isolatable components and subsystem groups allows

4.11 (Continued)

further refinement and elimination of subsystem approaches without going through full system detail analyses, since effects of the subsystem grouping on the total system may have been minor when compared to the variations between subsystem groupings.

4.12 Phase II Systems Integration

This section used more highly refined data in the systems integration and enabled the major groups to be matched using fewer possibilities. An additional specification review was carried out at this point to check system performance. Before extensive loop optimizations were carried out, the accuracy of the conclusions desired was questioned. This included a re-evaluation of the subsystems and specification accuracy and time availability. Provision was made for this in the original program plan.

If extensive optimizations were to be made (such as solution of optimum radiator outlet temperature), these were carried out in the optimization and trade-off section so that all previous data on subsystems could be utilized. If less detailed accuracy was desired, the candidate systems were summarized, with rejects made if possible.

4.13 Phase III - Final Systems Selection

Where two or more integrated systems for the same module were defined, a final system was selected where a clear choice was possible. In cases where no clear-cut choice was possible (i.e., between a low weight system of fair availability and a higher weight system of slightly better availability), both systems were utilized in the study. Specific recommendations were then made to point out areas requiring further research in order to arrive at a definite choice between these systems.

4.14 Summary

This study flow chart has been utilized to the fullest extent possible in performing the life support system study. The degree of optimization and final system definition provided was tempered by the time availability and the scope of the original effort defined by NASA. The overall study flow plan is applicable to studies of any size with the major difference being the degree of depth afforded each area. For large studies leading to final optimum system definition, the subsystem areas would be backed with feasibility testing and prototype hardware in some instances. However, the overall plan can be considered valid for sizing of a life support system and was the method utilized for this study.

5.0 SUBSYSTEM SUMMARY

5.1 General

This section presents the results of the subsystem study areas of the Mars Landing and Reconnaissance Mission Environmental Control and Life Support System Study in summary form. The subsystem analysis effort considered a wide range of potential crew sizes, mission lengths, and power penalties to make the data compiled usable for future modifications in the Mars mission, as well as the presently conceived mission. Thus, the subsystem study results (reference Volume 2 of this report) are applicable for crew sizes from 2 to 12 men, mission lengths up to 420 days, and power penalties of 200, 300 and 500 pounds per kilowatt. Since this report is intended as a summary of the study results to the basic specification, the discussion will confine itself to the individual 6-man design point for each of the three modules (MMM, MEM, and ERM).

The criteria for evaluating subsystems for further study and selection for use in the system portion of the study will aid understanding of the results of this study. The planned earliest date of launch for the Mars mission is 1973. Therefore, there is a 9 year period available to select and develop the subsystem discussed here. If proper effort is devoted to the task, any of the concepts considered should be capable of being developed for use on this mission. Therefore, present development status is not very important. However, since the mission duration is 420 days or longer, the ability to operate satisfactorily for long periods of time is important. This means that simplicity and ease of maintainability are important parameters. Another important parameter is the total equivalent weight which is composed of the equipment fixed weight, the weight of expendables required for the mission, and the weight equivalent of the power required to operate the equipment. Therefore, the most important selection criteria for these subsystems are total equivalent weight, simplicity, and ease of maintainability. In general, the various subsystems considered were first compared on a total equivalent weight basis. Then the most promising systems (based on total equivalent weight) were compared in regard to their relative simplicity of design and operation, as well as ease of maintainability for a long duration mission. After these comparisons were made there were still instances where final subsystem selection was not completed until the most promising subsystems (based on total equivalent weight, simplicity and maintainability) could be evaluated on an integrated complete system basis. As an example, a CO_2 removal subsystem selected on the basis of total equivalent weight, simplicity, and maintainability may not prove to be the optimum selection when the question of integrating the subsystem with the overall CO_2 management system is considered. This section discusses all of the subsystem concepts evaluated under any particular requirement, and the conclusions reached about each concept. More detailed information may be found in Volume 2 of this Report.

5.1 (Continued)

Bar charts are used in several of the following sections to illustrate the relative weight of the various sub-systems. Figure 5-1 shows the key which should be used to interpret these charts.

BAR CHART KEY

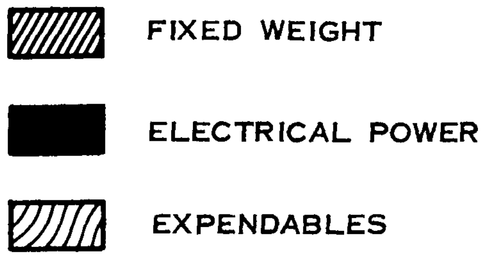


FIGURE 5-1

5.2 CO_2 Removal

The sub-system study on CO_2 removal equipment considered six basic approaches: solid adsorption, liquid absorption, cryogenic freeze-out, mechanical freeze-out, membrane diffusion and electrodialysis. These were evaluated to determine fixed weight, power, and expendable requirements for the Mars mission. Each of the systems will be briefly discussed to illustrate the major conclusions reached. The discussion will consider CO_2 removal alone to present the comparison for those systems where oxygen reclamation from the CO_2 is not required.

In addition to the above CO_2 removal devices, several non-regenerable removal systems were evaluated for use in the Earth Re-entry Module. These devices, however, are too heavy for missions greater than 15 to 20 days. Therefore, these non-regenerable devices will not be discussed in this section but will be covered in the discussion of the Earth Re-entry Module System in Section 6.4 of this volume.

5.2 (Continued)

The solid adsorption system utilizes a solid material known as a molecular sieve or zeolite to adsorb CO_2 from the process air. The adsorbed CO_2 is retained in the microporous structure of the material during the adsorption cycle. The CO_2 may be removed from the zeolite by exposure of the material to vacuum or by the addition of heat to the bed, thereby regenerating the material for further adsorption. Since the zeolite material shows a greater affinity for moisture than CO_2 the system also utilizes a drying material up-stream of the zeolite beds to protect the beds from moisture and potential subsequent poisoning of the beds. Parallel beds of each material are provided to assure continuous operation by cycling of the beds.

This system approach has been the subject of considerable development work, and offers the most advanced state-of-the-art for missions not requiring CO_2 reduction to oxygen. The primary development area to be considered is long-term reliability; although successful tests have been run at Hamilton Standard for periods up to 50 days with no deterioration of the system or the chemicals.

The liquid absorption system utilizes a chemical reaction of the CO_2 with a circulating liquid as the removal method. The process air is brought into contact with the liquid where the CO_2 reacts with and is carried off by the liquid. Addition of heat to the circulating liquid is sufficient to free the CO_2 and regenerate the system. The CO_2 contains an amount of water vapor which must be condensed and separated out prior to exhausting the CO_2 to space. The liquid is continually recirculated throughout the system to provide continuous operation.

This system approach is an extension of the technology currently used in submarine systems. Liquid absorption systems have proven quite successful for submarine applications but no development work has been expended to make the systems operational under zero gravity conditions. The weight and power of a zero gravity unit have been estimated for this study. It can be seen from these estimates that the potential size and equivalent weight make it a desirable candidate, if the approach can be successfully developed.

The cryogenic freeze-out CO_2 removal concept is based on the utilization of the cryogenic oxygen storage as a heat sink for freezing the CO_2 from the circulating air stream. Processed air enters the system, is pre-dried by a desiccant bed to prevent water freeze-out along with the CO_2, and is processed through a freeze-out heat exchanger where the CO_2 is collected. Alternate heat exchangers are utilized for continuous operation (one is regenerated by sublimation to space or planetary atmosphere while the other is collecting the CO_2). This system approach is not

5.2 (Continued)

considered suitable for the Mars Mission Module or any other vehicle which utilizes CO_2 reduction to oxygen, since these systems will not have the large source of cryogenic fluid available without serious penalty to the system. However, this system is of interest for use on the Mars Excursion Module where large amounts of cryogenic fluids will be required for the fuel cell and for spacecraft atmosphere make-up. Therefore, parametric data were prepared for this approach so it could be considered in the system integration for the MEM.

The mechanical freeze-out system approach for CO_2 removal utilizes a heat exchanger and a compressor coupled to an air motor (or expander) to freeze the CO_2. The CO_2 is regenerated from the collector by addition of warm process air through one pass of the collection heat exchanger. The system is not considered a promising candidate for the Mars application due to its high power requirement and the inherent reliability problems.

Membrane diffusion CO_2 removal utilizes diffusion through thin-walled membranes more permeable to CO_2 than air as the separation device. A system which provides concentrated CO_2 utilizes several membrane stages with interstage compressors to pump the CO_2 from one stage to the next. As a result of the compression requirements, the interstage compressor power is quite high at the present, thus making this approach non-competitive from an equivalent weight viewpoint.

Membrane diffusion state-of-the-art is in the early stages at this time with membrane construction and material selection as well as the overall power requirement representing major problems. No significant advantage exists to make development of this system worthwhile for this application.

Electrodialysis CO_2 removal utilizes electrochemical reactions to convert the CO_2 to ionic species which then migrate out of the absorption zone through membranes prior to reforming as CO_2 gas. The CO_2 gas is then swept from the surface of the membranes by a circulating water stream and removed from the water by separation devices. Design of these separation devices for zero "g" operation is the primary problem area of this approach. The water rate is quite high leading to creation of the CO_2 bubbles in the liquid flow. Present humidity control water separator concepts are not adequate solutions to this problem because they depend on the major portion of the stream being gas with only a small percentage liquid. In this case the stream is predominantly liquid with entrained bubbles. The overall reaction also converts a portion of the water into hydrogen and oxygen, providing a side benefit of oxygen production if the excess water is available to meet the electrodialysis make-up requirement. However, this also introduces a side problem,

5.2 (Continued)

i.e., the separation and disposal of the hydrogen produced.

Electrodialysis has a severe penalty when considered for CO_2 removal alone in systems not requiring water electrolysis. However, if electrolysis is required, the approach is competitive with others considered above.

The primary problem areas associated with this system are the design of the CO_2 gas liquid separator and overall reliability and system life. For requirements where oxygen regeneration from the CO_2 is not required, this system cannot be considered competitive at this time on an equivalent weight penalty basis.

Figure 5-2 presents a summary comparison of the six systems considered for CO_2 removal. This figure illustrates the fixed weight, power and expendable requirements of each of the system approaches for a six man design point for a 420 day mission.

CARBON DIOXIDE REMOVAL

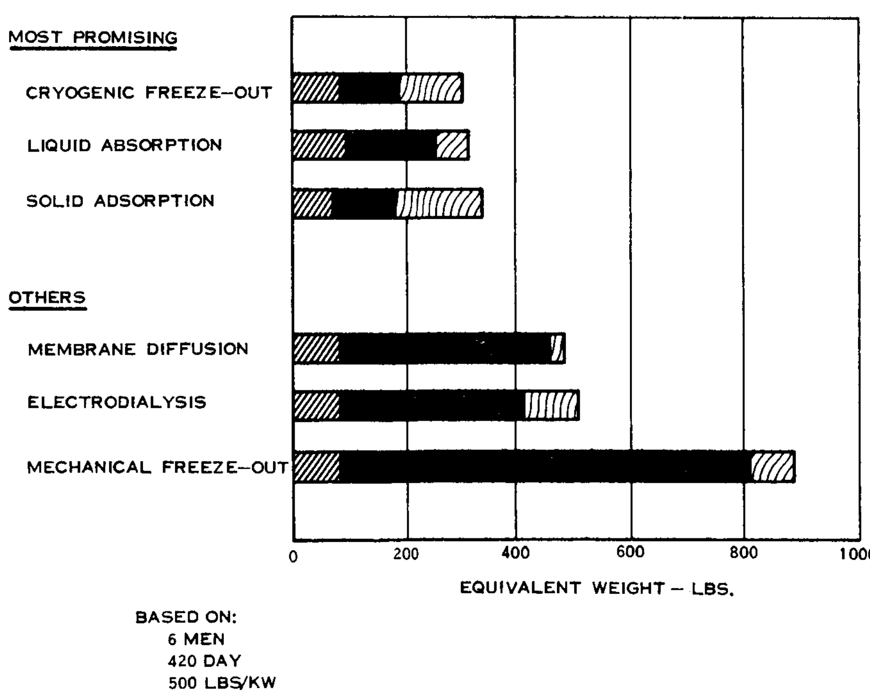


FIGURE 5-2

5.3 CO_2 Removal And Transfer

When reduction of the CO_2 to oxygen is considered for the integrated system, addition of transfer equipment is required to provide transfer of this CO_2 to the reduction system. When removal and transfer are considered, only three of the six systems studied appear competitive from an equivalent weight point of view. The electrodialysis, liquid absorption, and solid adsorption systems are the most promising for integration with CO_2 reduction equipment. Mechanical freeze-out and membrane diffusion are not attractive for this requirement due to their high power requirements. Cryogenic freeze-out which is competitive from a weight basis for systems not recovering oxygen, is not competitive for systems which recover oxygen. This is due to its dependence on a large amount of cryogenic oxygen storage which is not probable with a system utilizing CO_2 reduction.

In the Mars Excursion Module, on the other hand, where the fuel cell is used as a source of power, the use of cryogenic freeze-out is feasible.

Figure 5-3 presents the weight comparison of the three candidate systems. Electrodialysis is quite competitive for integrated CO_2 management use since its oxygen generation feature is a distinct advantage in this case. The CO_2 leaving the electrodialysis cell must be of high concentration and dry for some of the reduction systems requirements; therefore, it may be necessary to further penalize the system with desiccant beds which depend upon the end selection of a reduction system (the penalty for the desiccant beds was included only in Figure 5-6). Solid adsorption is the lightest of the three approaches and offers the largest potential of the three systems since the outlet CO_2 is delivered in a dry form and therefore it may be mated with any of the presently conceived reduction system approaches. For use with CO_2 reduction, the molecular sieve bed of the solid adsorption system must be desorbed by a vacuum pump or the addition of heat. This penalizes the system when compared to its application as a CO_2 removal system alone, since either of these desorption methods requires power. For this study, heated regeneration has been selected as the optimum method of molecular sieve desorption.

5.4 Water Electrolysis

A review of the various schemes for zero gravity water electrolysis was conducted at the subsystem level to provide design data for system integration studies. The actual process of electrolysis of water to hydrogen and oxygen is quite similar in all of the approaches considered, with the major difference being in the solution to the zero gravity operation problem. Electrolysis systems are of primary interest for two applications. For long duration missions electrolysis provides a feasible alternate oxygen generation device which replaces conventional oxygen storage.

5.4 (Continued)

CARBON DIOXIDE REMOVAL AND TRANSFER

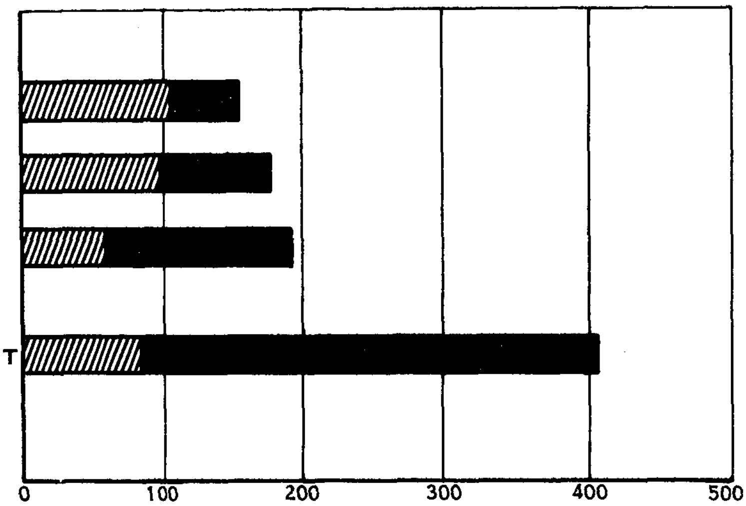


FIGURE 5–3

Water storage is quite simple compared to the storage of oxygen in either the cryogenic or gaseous state. The water electrolysis system is also utilized with certain CO_2 reduction systems which generate water as an intermediate product. This water must then be electrolyzed to provide the final oxygen supply. This study attempted to determine design weight and power requirements for electrolysis systems for use in system integration.

Five basic approaches were considered for this requirement, Figure 5-4 presents a comparison of the approaches considered. The most promising systems investigated are the organic membrane and porous electrode cells. The organic membrane cell utilizes perm-selective membranes to permit passage of the hydrogen ion but not the hydroxyl ion as the method of separation of the gases. In the porous electrode cell, the water is fed to the system through wick distribution equipment and the gases are separated by electrodes which prevent liquid passage, thus reducing water carryover to the vapor with which the gases are saturated. These two approaches present the most advanced state-of-the-art of the systems considered and the least complex for zero "g" application, and consequently, were selected as potential candidates.

5.4 (Continued)

The porous electrode cell was selected for use in system integration work due to its greater potential weight and power savings. This cell, operating at very high efficiencies, represents close to the practical limit for electrolysis cells and was selected based on this predicted performance. The organic membrane cell must be considered as a back-up approach if the predicted potential of the porous electrode cell cannot be met.

All of the other approaches are considered research equipment at this time. The hydrogen diffusion cell utilizes an artificial gravitational field to separate the oxygen and a diffusion cathode to separate the hydrogen. The rotating cell creates gas/liquid separation by the artificial gravitational field. Finally, the vortex separator cell utilizes a pair of contoured wall vortex separators mounted axially on either side of a diaphragm for gas separation. Electrolysis is carried out on either side of the diaphragm and the gases generated are separated by this diaphragm. These

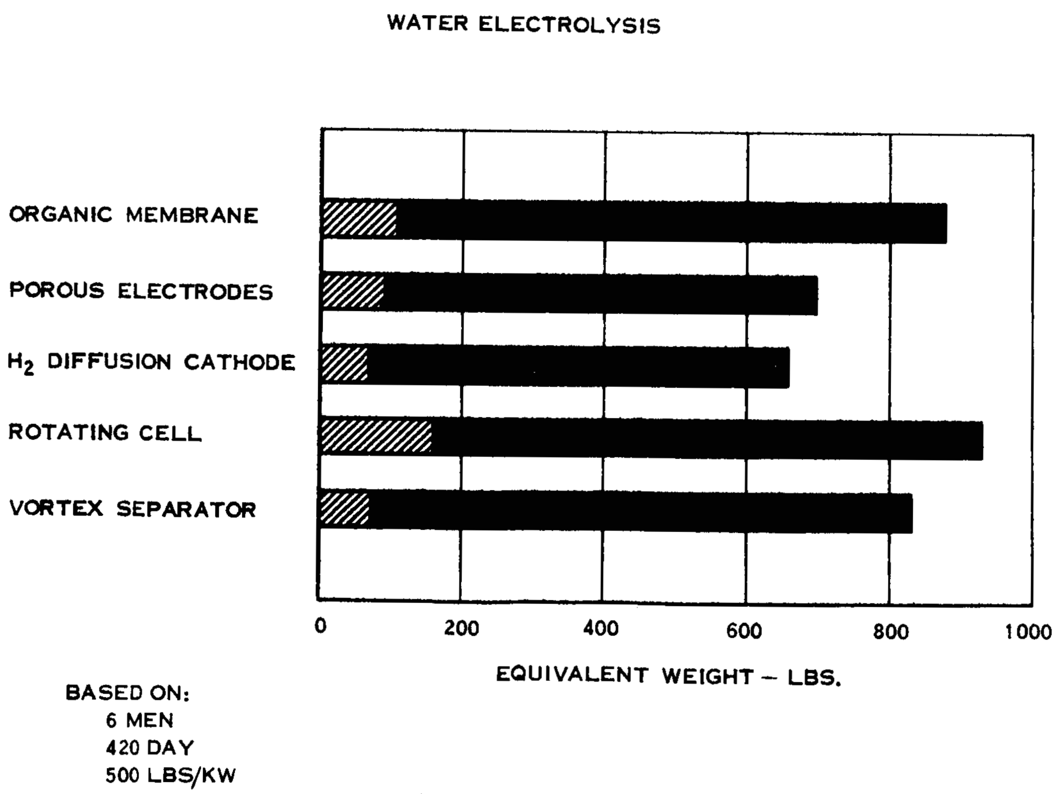


FIGURE 5-4

5.4 (Continued)

cells, although somewhat attractive, do not exhibit sufficient potential to justify their development at this time, assuming the porous electrode predicted performance can be achieved.

5.5 CO_2 Reduction

The analysis of CO_2 reduction equipment considered five major concepts as potential candidate systems. The five: decomposition by radiation, hydrogenation, the methoxy (Sabatier) reaction, solid electrolyte, and molten carbonate electrolysis, were analyzed to determine applicability and suitability to the Mars requirements. At this state of the study, it was assumed that concentrated CO_2 is the input gas to the reduction system and the end product is oxygen. Therefore, no consideration was given to integration of the removal system, but for systems with electrolysis requirements, the electrolysis penalty is included. Section 5.6 describes the integrated management system results.

The CO_2 reduction equipment is one of the heaviest of the life support subsystems. Therefore, it deserves very careful consideration so the optimum method can be selected. Most of the work being done in this field is in the research phase, and testing is done with breadboard hardware. In many instances, the total testing time is in the order of hours rather than the months or years which will be necessary prior to the Mars mission. It was necessary to evaluate this work and predict the weight and performance of these various reduction schemes as space flight hardware systems. This section presents these results.

The hydrogenation or Bosch reaction utilizes a high temperature catalytic reaction of the CO_2 with hydrogen to form carbon and water. This water is then electrolyzed into oxygen and hydrogen with the oxygen supplied to the cabin system and hydrogen recycled to the reactor to maintain the reaction. The catalyst is the prime expendable in the system and must be replaced periodically for adequate system operation. Optimum catalyst utilization rates are the primary unknowns of this system. Hydrogenation has received considerable research attention throughout industry and probably enjoys the most advanced state of development of any reduction system. Decomposition by radiation using thermal or nuclear energy was briefly analyzed for applicability to this requirement. The CO_2 is initially decomposed into carbon monoxide and oxygen. The carbon monoxide is then further reacted to form CO_2 plus carbon with the carbon disposed of, and the CO_2 recycled to the initial reaction. This system is in the earliest conceptional stages and there is not enough information available to perform a parametric analysis. The system may be usable on nuclear power supply vehicles, such as the mission module, but does not appear attractive

5.5 (Continued)

at this time due to the complexity of the equipment necessary to perform the irradiation.

The methoxy or Sabatier process reacts the CO_2 with hydrogen to form methane and water. The water is electrolyzed into hydrogen and oxygen with the hydrogen recycled and the oxygen supplied to the cabin. The methane by-product presents the major problem. Present systems have achieved success only by disposing of the methane which represents a high expendable penalty to the Sabatier system. Other methods of methane decomposition to reclaim the hydrogen include direct reduction to carbon and hydrogen, conversion to acetylene and hydrogen with the acetylene dumped to space, and further reaction with CO_2 to form carbon and water. None of these three methods has achieved any success in laboratory operations to date. Until this is done, the Sabatier system must be ruled out for the Mars mission due to the high use rate of expendables.

The solid electrolyte CO_2 reduction system converts the CO_2 into carbon monoxide and oxygen in the reactor and then catalytically dissociates the CO into CO_2 and carbon. From this point, the CO_2 is recycled to the inlet of the reactor and the carbon is disposed of. This system appears very attractive for the Mars mission due to low fixed weight and low expendable rate, resulting in the lowest total equivalent weight of any reduction system.

The primary development problem which may exist is the life and durability of the solid electrolyte tubes. However, it is felt that these problems can be solved by the 1973 launch date if adequate development effort is devoted to the problem.

The final system investigated is molten carbonate electrolysis of the CO_2. This system electrolytically dissociates the CO_2 into carbon and oxygen in a molten alkali carbonate. The oxygen is liberated at the anode while the carbon is deposited at the cathode. This system has also demonstrated the capability to remove the CO_2 from the process air stream at the same time thus eliminating the need for any CO_2 removal equipment. This comparison for CO_2 reduction alone does not take this into account although it is considered in the CO_2 management system section. The molten carbonate system is very competitive with the solid electrolyte system on a total equivalent weight basis. Although it is presently in the research stage, it is felt that this system can be developed, for the Mars Mission, to a point where it will offer the lowest equivalent weight method on an integrated system basis.

The problems which still remain to be solved are zero "g" operation of the liquid melt, expendable requirements of the electrode design, and carbon deposition efficiency. All of these are problems which can be solved by adequate development work and should not present a severe drawback to this system approach.

5.5 (Continued)

Figure 5-5 presents the equivalent weight comparison of the reduction systems for a six man system for a 420 day mission to Mars. It can be seen that solid electrolyte and molten carbonate are the most promising methods of CO_2 reduction.

CARBON DIOXIDE REDUCTION

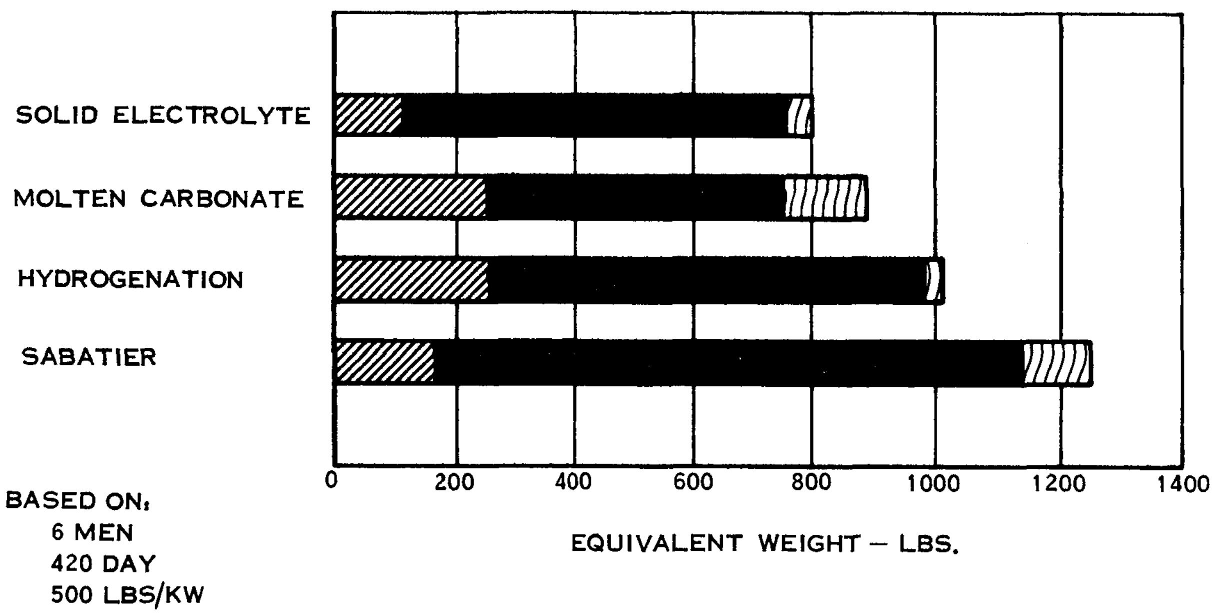


FIGURE 5-5

5.6 CO_2 Management

Figure 5-6 presents the results of the CO_2 management analysis. The figure presents three candidate reduction systems mated with three candidate removal systems to illustrate the overall range of potential systems for the six man, 420 day design point.

The systems listed as most promising were selected on the basis of minimum total equivalent weight to perform the overall CO_2 removal-reduction task. The other systems are shown for comparison purposes. It can be seen that the molten carbonate system is the lightest weight system from a total equivalent weight standpoint. It is about 60 pounds lighter than the nearest competitor, solid electrolyte-solid adsorption.

5.6 (Continued)

CARBON DIOXIDE MANAGEMENT

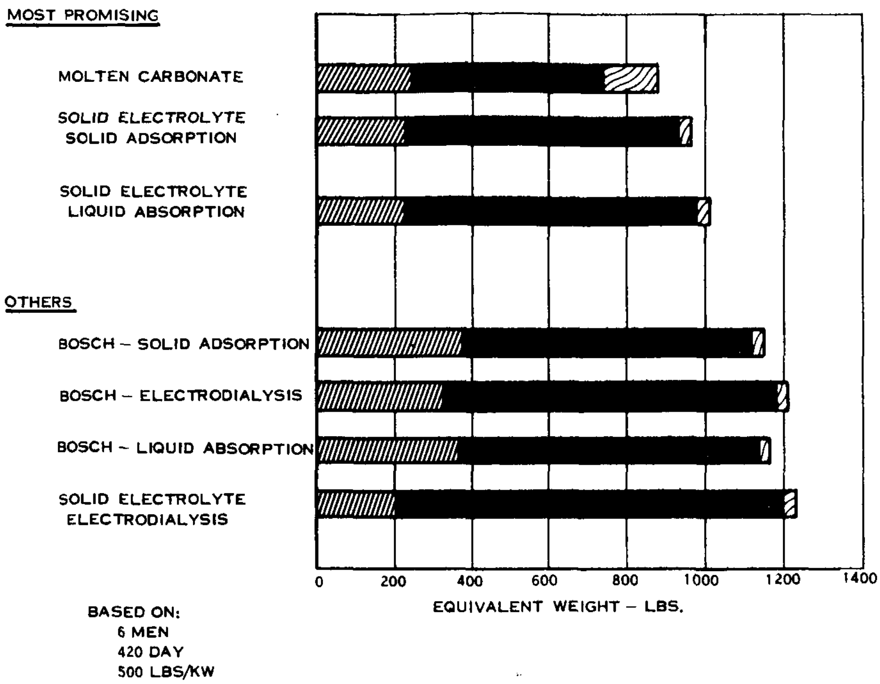


FIGURE 5-6

It should be noted that the primary differences in these two systems are in power used and expendables required. The power required can be decreased somewhat, but the primary weight reductions to be achieved are the expendables. The expendable rates shown here are those most likely to be attained by a normal development program. However, in the case of the molten carbonate system, it is theoretically possible to deposit solid carbon on the electrodes, and, assuming the electrodes can be reused, reduce the expendables to zero. This may require an extended development program, but it is theoretically possible and should be considered for launch dates of possibly 1975 or later. The expendables shown for solid electrolyte-solid adsorption may also be reduced by an extended development program. However, this expendable is a catalyst mesh on which the carbon is deposited and is

5.6 (Continued)

periodically discarded. Therefore, it is unlikely that the expendables could be decreased below about one half that shown. If both these reductions were achieved, the molten carbonate system would have a significant advantage over the solid electrolyte-solid adsorption.

5.7 Atmospheric Storage Systems

The subsystem study of atmospheric storage equipment was performed to derive meaningful design data for use in system integration rather than to determine final storage system design. The primary point of interest was the storage penalty as a function of the weight of the usable fluid stored. In general, five storage methods were considered as potential candidates for the metabolic, leakage, and repressurization requirements of the three Mars Modules. For each consideration, the evaluation was intended to determine the tankage weight and the power requirements for fluid expulsion over a range of potential fluid storage quantities. Separate storage of the oxygen and nitrogen as supercritical cryogenic, subcritical cryogenic with thermal pressurization, subcritical cryogenic with positive expulsion, and the gaseous state were considered as the potential candidates. In addition, brief consideration was given to mixed storage of both constituents in a single container.

Supercritical cryogenic storage is the method currently being used for manned space system atmospheric supply requirements. The fluid is stored at an elevated pressure where the mixture is homogeneous (no phase distinction exists between different portions of fluid in the tank), thus eliminating vapor-liquid separation problems in zero "g". This system is the subject of considerable development work at this time for the current manned space programs.

Subcritical cryogenic storage with thermal pressurization is a two phase storage method which presents vapor/liquid metering problems in zero gravity but offers a definite weight advantage over supercritical storage. The system must be designed with proper metering and heat exchange equipment to provide a constant gaseous supply to the cabin. Initial feasibility testing indicates that this is very probable and should not present a major design problem. This method of subcritical storage is in early development stages compared to its supercritical counterpart, and will therefore require a more extensive development program before it will be ready for operational use. This is not a problem for a 1973 launch date.

Subcritical storage utilizing positive expulsion methods incorporates a pressurized bladder or piston device to assure a liquid delivery to the metering valve. The weight is essentially the same as subcritical storage with thermal pressurization, and the concepts are similar. This approach presents definite problems in bladder

5.7 (Continued)

or piston design to assure adequate overall reliability. Since no weight advantage is evidenced over the subcritical system with thermal pressurization, this system was not considered a candidate for the Mars Mission. However, it should be kept in mind as a possible back-up system in the event that serious problems arise in developing thermal pressurization.

The last method of separate storage of the constituents is in the gaseous state. Storage as a gas at high pressure presents the most positive delivery method, since the constituents are available essentially on demand; however, due to the high pressure requirements, the overall system weight penalties are high and generally unattractive for long missions. However, this method is definitely a candidate for the Earth Re-entry Module where the mission is short and there is a long time period between utilization of the stored contents.

Finally, a brief analysis of mixed storage of both constituents in one tank was considered. This approach was discarded due to its great dependence upon stable use rates of both constituents. This system is attractive for vehicles where leakage is relatively constant and crew activity minor or of a short duration. However, in the case of the Mars vehicle where crew variations may range from 2 to 6 men, the system in unattractive due to its constant mixture delivery.

Figure 5-7 presents the equivalent weight comparison as a function of useful fluid weight for the subcritical, supercritical, and gaseous storage methods for each of the three vehicles. It can be seen that subcritical storage offers a very clear advantage for the Mission Module where the use of atmospheric stores begins within 15 days of filling the tanks and extends for 420 days. In the case of the Mars Excursion Module, the mission duration is only 40 days, but the use rate is high because oxygen is not being reclaimed from CO_2. Even though there is a hold time of 120 days prior to use of the fluid, the subcritical storage still offers the lowest weight. For the Earth Re-entry Module, the tanks must hold the oxygen for 420 days prior to use, and must contain only enough for a three day mission. For this case supercritical storage is slightly lighter than subcritical storage; however, gaseous storage is only slightly heavier than either of the cryogenic methods. Therefore, the simplicity and resulting reliability of the gaseous system may warrant its use.

5.8 Water Reclamation

The analysis of water reclamation equipment at the subsystem level provided an indication of the relative penalties for reclaiming urine, wash water, and the recovered condensate from the humidity control system. Each of these sources was treated separately, since the degree of contamination varies considerably for

5.8 (Continued)

OXYGEN STORAGE

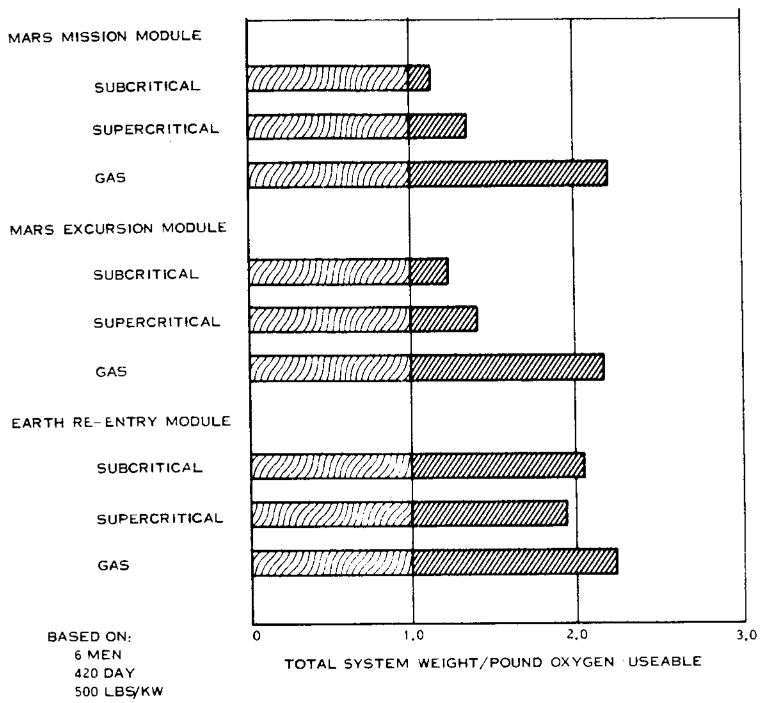


FIGURE 5-7

each approach. The discussion will take three parts: first, urine reclamation; secondly, wash water reclamation; and finally, the method of humidity water reclamation.

For urine reclamation, six approaches were considered as candidates for the Mars vehicle. The analysis investigated the fixed weight, power, volume, and reclamation efficiency of each approach to determine overall suitability. The initial analysis did not penalize any approach for the amount of water not recovered. However in the system integration phase of the study, each system was penalized for this since it was a study ground rule that water of oxidation could not be used.

The electrodialysis system utilizes alternate pairs of anion and cation permeable membranes to remove electrolytes from the process liquid. Non-electrolytes are

5.8 (Continued)

removed by filtration prior to the electrodialysis stack. The process is essentially a batch process, since the liquid is recirculated through the stack until the required degree of desalinization is achieved. The urea is precipitated out of the process flow prior to the electrodialysis stack and removed by a series of activated charcoal filters.

The electrodialysis method is a low weight, low power system with a relatively simple operational procedure. The primary draw-back with this system at this time is the high amount of expendables required for removal of the urea. The charcoal requirements are such that, under current estimates, the system in non-competitive. Some degree of optimism exists on the possibility of regeneration of this charcoal. This has not been proven to date; however, if it can be demonstrated that the urea can be separated from the charcoal, the system becomes a candidate approach for the mission module system. Reliability is another potential problem with the electrodialysis system, since membrane life for long term operation has not been demonstrated with urine reclamation systems. The commercial counterpart of this system has achieved long membrane life for brackish water reclamation considerations, but the extrapolation from one requirement to the other may not be valid.

The air evaporation system is the simplest approach considered in this study and rates as the prime candidate for this application. A wick evaporator is utilized to evaporate the water in the urine into a circulating air stream. This air stream may be a separate closed loop or a portion of the main thermal and atmospheric control system.

The analysis has considered both open and closed loop systems in order to keep the various sources of water separate to improve reliability in the event of malfunction of one of the reclamation systems. Potential weight advantages exist for open system operation; however, available heat and system integration must be considered to provide the right reclamation system for each EC/LSS integration. The evaporated water is condensed and recovered by a water separator similar to the equipment in the main thermal and atmospheric control system. The contaminants in the urine remain in the wick and are removed by periodically changing wicks.

This system has demonstrated excellent performance results with laboratory breadboard and prototype equipment. Reclamation efficiency is essentially 100 per cent, which makes it very desirable. A possibility of partially regenerating the wicks exists for this system which would further reduce the expendable requirements in the future. Fixed weight and power requirements are quite low and start-up and shut-down procedures are quite simple.

5.8 (Continued)

The ELF system (electrolysis-fuel cell) for water reclamation electrolyzes the urine into hydrogen and oxygen and then utilizes these constituents as fuel for the fuel cell which produces water as part of the power generation process. This system, although simple in theory, utilizes the most complex equipment of all the water reclamation systems considered. In addition, it is a high power consuming system even when the system is given credit for the power generated by the fuel cell. The study eliminated this approach at the subsystem level due to this non-competitive equivalent weight and the reliability problems associated with long term electrolysis/fuel cell combinations as opposed to the more competitive approaches considered.

The vapor compression system evaporates the water in the urine, compresses it to add energy to the system and to raise the condensing temperature (thus allowing regenerative heat transfer) and then condenses it to provide liquid water. The system analyzed utilizes a rotating evaporator-condenser combination to solve the zero "g" problem. The contaminants in the urine appear as scale on the evaporating surfaces. The system is quite complex when compared to other candidate water reclamation approaches and has an elaborate start up and shut down procedure. This procedure makes it undesirable for a system which normally operates only part of the time, allowing for periodic maintenance or excess capacity for make-up in the event of system malfunction.

Vapor compression enjoys a relatively good prototype status but much needs to be done prior to achievement of flight type hardware. The expendable requirements for pretreatment, evaporator scale removal, and atmosphere lost during condenser purging must be carefully analyzed and subjected to considerable design work to make the overall system approach competitive. It offers an attractive equivalent weight comparison with the other systems analyzed when it is not penalized for unrecovered water. However, when penalized for this unrecovered water, it becomes non-competitive. In addition, inherent reliability and treatment problems make it less attractive than the air evaporation or electrodialysis systems.

Another form of vapor compression utilizes an oil stream as the carrier medium. The urine is flashed across a nozzle into a circulating oil stream. The vapor and oil are separated, the vapor compressed and condensed, and the oil reheated and recycled to continue the evaporation process. This circulation loop modification utilizes the oil as the evaporator surface to prevent scale buildup and allow scale removal by filtration. This system is attractive from a total equivalent weight point of view when not penalized for unreclaimed water, and only slightly less attractive when penalized. However, it requires considerable development work on the oil-water mixing contactor and has inherent start-up and shut-down problems. Therefore, from an overall desirability viewpoint this system is somewhat less attractive.

5.8 (Continued)

The final urine reclamation system considered is vacuum distillation. In this approach, the urine is evaporated in a boiler, passed over a high temperature catalyst for purification and condensed by a zero "g" condenser. In theory the system operation is quite simple, but problems of zero "g" operation make it unattractive. The majority of the test data comes from laboratory testing and cannot be considered representative of flight type equipment. Little or no work has been done on the zero "g" condenser as a part of this system, and with present condenser effectiveness ranges it cannot be considered as a candidate for the Mars application.

For the Mars Mission Module the ground rules stated that the water of oxidization cannot be used. Therefore, to compare the various systems, the unrecovered water must be included as an additional penalty to the system. Figure 5-8 presents the comparative weights for the various systems including the penalty for unreclaimed water. This comparison is based on a six man, 420 day design point. It is clear from this illustration that the air evaporation and oil jet evaporation are the most promising systems.

WATER RECLAMATION – URINE
SYSTEM CHARGED WITH PENALTY FOR UNRECLAIMED WATER

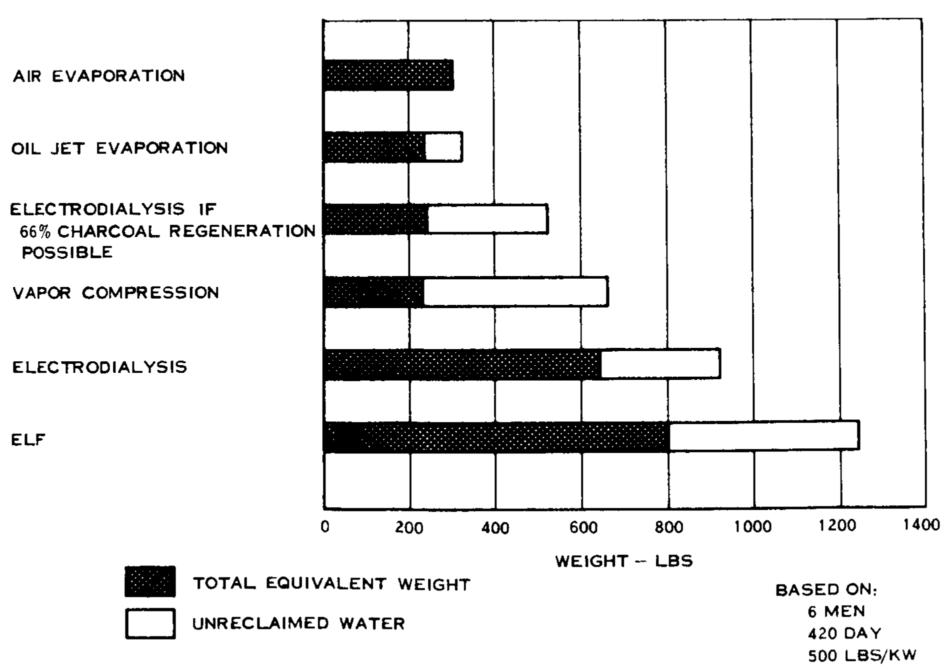


FIGURE 5–8

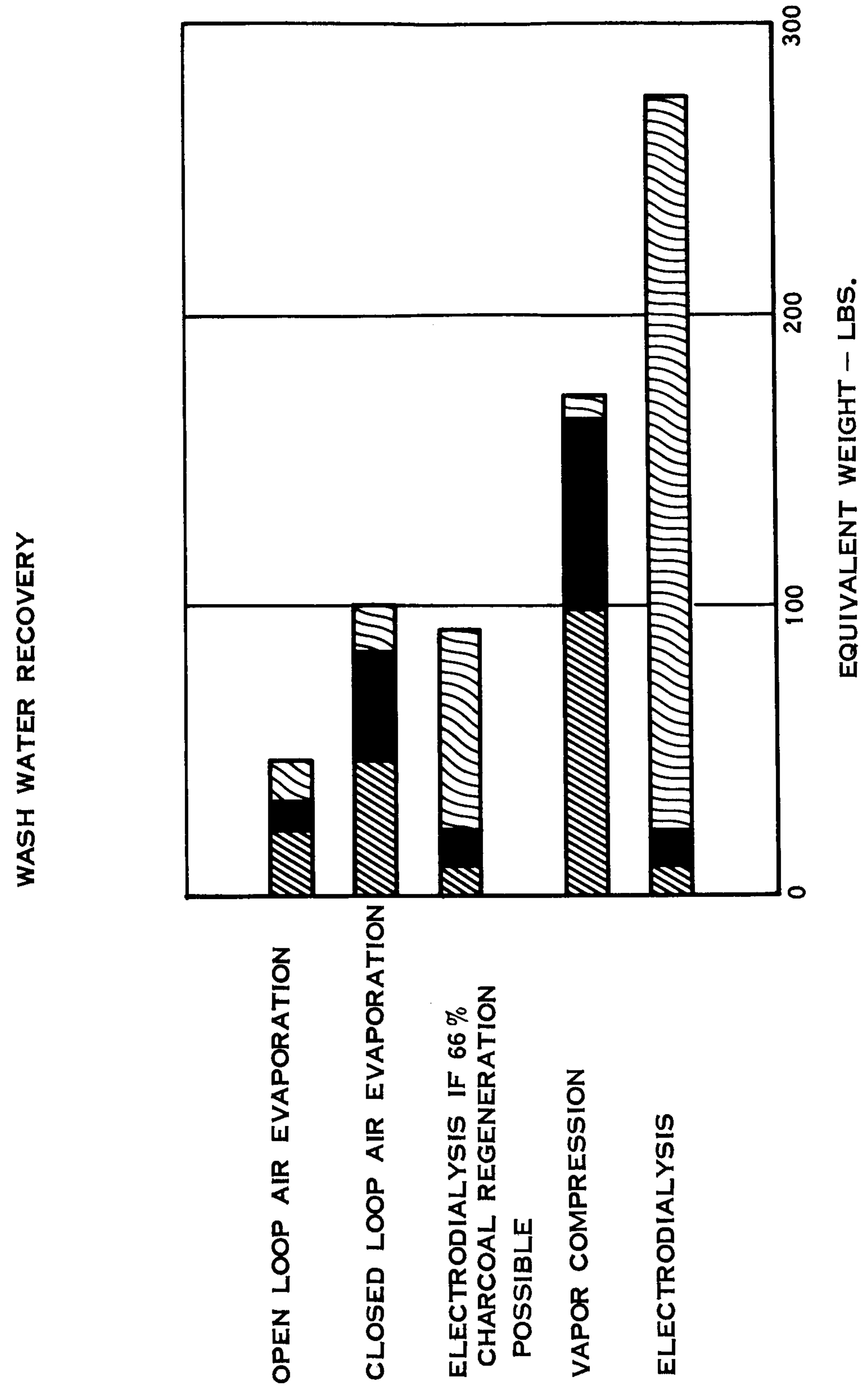
5.8 (Continued)

On long duration missions such as the journey to and from Mars, consideration must be given to bathing the crew. It is apparent that washing by impregnated pads for this period of time is psychologically undesirable, and the weight of the pads becomes prohibitive. Therefore, some means of washing with soap or detergent and water was considered. Depending on the method selected, the wash water requirements will range between 14 and 40 pounds per man day. It was decided that, from a reliability standpoint, it was desirable to keep this water in a potable condition so it could be used for drinking in the event of a urine reclamation system malfunction.

The contaminants removed from the body are independent of the amount of wash water used. Therefore, the contaminant level of the wash water is an inverse function of the amount of water used. It has been calculated that the contaminants in the water can be kept below the 500 ppm maximum acceptable level if 14 pounds per man day are distilled and any additional water can bypass the reclamation system. However, it is necessary to remove the soap odor from all the water. Therefore, the wash water analysis was done on the basis of 14 pounds per man day being processed completely, and the other 26 pounds being processed by filtration through an anionic resin and charcoal bed. The entire water storage tank is held at 140°F to 160°F to kill most of the bacteria which might be in the bypass water and to prevent new bacteria from growing.

The electrodialysis system does not use the 26 pounds per man day bypass, but processes the entire 40 pounds per man day. The reason for this is that the size and power of the electrodialysis unit is a function of the contaminant removed rather than the total water processed, and a 40 pound per man day unit is essentially the same size as a 14 pound per man day unit for the same total contamination level.

The three systems analyzed for recovering wash water are air evaporation, electrodialysis, and vapor compression. There are two types of air evaporation (open loop and closed loop) and two ways of analyzing electrodialysis (assuming regeneration of charcoal and no regeneration). This makes a total of five different concepts. A total equivalent weight comparison for these five concepts in shown in Figure 5-9. It can be seen that open loop air evaporation, electrodialysis with charcoal regeneration (assuming 66% regeneration can be achieved), and closed loop air evaporation are the lowest weight systems.



BASED ON:
6 MEN
420 DAY
500 LBS/KW

FIGURE 5-9

5.8 (Continued)

The humidity water system is constantly operating,removing water from the cabin atmosphere to control the humidity. This water is then processed and sent to the potable water storage tank.

It is anticipated that the humidity water will be basically pure with only a minimum of processing required. Processing should consist of filtration for particulate removal and filtration through charcoal and ion exchange resins for control of odor and taste.

In the Mars Excursion Module water reclamation was not feasible. It was decided that the total water requirement could be met by a combination of humidity water and fuel cell water. This combination was included in the interest of reliability.

The Earth Re-entry Module would receive its required water from the mission module which will have a more than adequate supply for the ERM at the termination of the MMM's phase of the overall mission.

5.9 Waste Management

The waste management study at the subsystem level was concerned with methods of treatment and storage of feces. Although a considerable amount of other wastes will be present in the space vehicle, the prime treatment problem is in the fecal matter.

The methods of processing considered are simple storage of the feces, storage with a germicide treatment, distillation and pyrolysis of the feces to reclaim the moisture, incineration as a moisture reclamation device, and microbiological treatment. Since the ground rules of the study prohibit the use of fecal water, those methods which reclaim the water cannot be considered for use on the Mars vehicle. However, the information is presented here to indicate the potential savings in weight which could be realized by using this water. Figure 5-10 shows this weight as a function of mission duration.

Simple storage was considered unacceptable since it presents bacteriological and odor problems to the overall vehicle. The feces contain pathogenic bacteria that would multiply rapidly at normal room temperature and the presence of such material in the spacecraft would constitute an unacceptable hazard to the health of the crew in the event of a rapid depressurization and possible bursting of storage containers. The storage containers would have to be pressurized and leakproof or vented to the contaminant control equipment since unpleasant or odorous gases are generated by the untreated feces.

5.9 (Continued)

WASTE MANAGEMENT

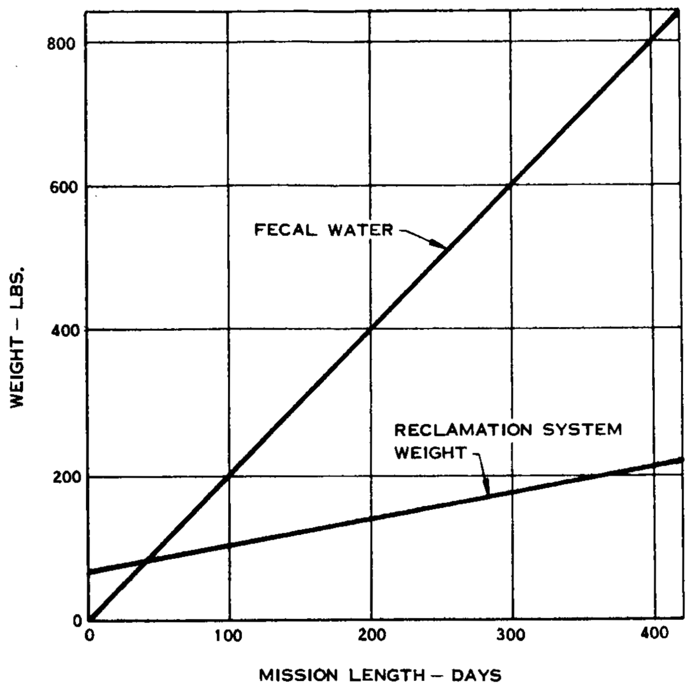


FIGURE 5-10

The most acceptable treatment of feces deemed suitable for space flights is simple storage of the feces following thorough mixing with a germicide. By virtue of chemical treatment immediately after collection, there is minimum danger from pathogenic organisms. A suitable chemical preservative is Weladyne, prepared by West Chemical Products, Inc. This is a type known as iodophor, consisting of a complex formed by attachment of iodine to large, surface active organic molecules. This provides positive killing action against all kinds of bacteria, including spore forming types.

If it is desired to reclaim the moisture from the feces, it can be done by distillation and pyrolysis or incineration.

5.9 (Continued)

The distillation and pyrolysis method of recovering this water is a light weight method and utilizes the water savings illustrated by Figure 5-11. One problem observed in these systems is the distinct fecal odor of the effluent water. This will not necessarily be a problem if this water were to be used in an electrolysis cell to produce oxygen, but it would be a problem if the recovered water were to be used for drinking. This would require additional charcoal filtration.

Incineration of the feces was also analyzed as a potential water reclamation method, but was found undesirable due to the weight and power required for complete combustion of the fecal material. A total equivalent weight requirement of 206 pounds per man was found to be required for incineration. For a six man crew this is 1236 pounds, which far exceeds the 830 pounds of fecal water which could be recovered for a 420 day mission.

Microbiological treatment of waste products was considered briefly. In this system organic waste compounds are used up by biota in supporting microbiological metabolism either in the presence or absence of free oxygen. The penalties for such a system are high if water is the only product recovered. This method becomes more attractive if it is considered for a completely closed ecology where the carbon is recycled and integrated with a photosynthesis unit.

Therefore, for all three Mars modules, simple storage of feces following thorough mixing with a germicide was selected. In addition, for the MMM, the distillation and pyrolysis method of recovering fecal water was suggested for inclusion in the system.

5.10 Temperature and Humidity Control

At the subsystem level, the study of temperature and humidity control equipment was concerned primarily with providing generalized design data for use at the system level. The weight and power requirements for fans, water separators, and heat exchangers were analyzed and identified in parametric form wherever possible.

In the case of the space radiator, no specific design can be made at the subsystem level so the attention was concentrated on the identification of the various requirements for the radiator, and selection of candidate concepts. The study considered coolant and coating selection, meteoroid protection methods, reliability analysis and criteria, tube configuration, and influx variation throughout the mission. By elimination of non-candidate approaches for many of these functions the study provided useful design data for the final system definition phase.

5.11 Contaminant Control

The contaminant control analysis at the subsystem level was concerned with the identification of potential contaminants and methods of their removal. The analysis was developed primarily around the potential metabolic contaminants, due to lack of sufficient data on the vehicle equipment and experimental source contaminants to be expected from the ultimate vehicle. The effects of these contaminants were considered in sizing the overall contaminant control system, but must be further defined before final sizing can be accomplished. The results of the study indicated that, for complete contaminant control, a combination of four methods must be considered. These four (activated charcoal, particulate filtration, a chemi-sorbent bed, and a catalytic burner) should provide the required degree of safety for the end mission.

The words "should provide" are utilized here since, prior to final design, these other sources of contaminants must be further evaluated to assure that the contaminants and the potential production rates under emergency conditions can be handled by the overall control system. Secondly, the area of contaminant control for this application requires considerably more work before final capability of the combined system can be determined. Catalytic burner technology is to a point where the contaminants which may be oxidized into less harmful contaminants, or those readily removed by other removal equipment, can be identified and evaluated. The area of concern, however, is the removal method for those contaminants which cannot be oxidized or removed by activated charcoal or filtration. The use of a chemi-sorbent bed should effectively remove these other contaminants, but until considerable research work is done on the selection of absorbent materials, a full evaluation cannot be made.

Present technology indicates that the metabolic contaminants can be handled in this manner.

5.12 Instrumentation

At the subsystem level, the primary purpose of the instrumentation study was the determination of methods of detecting potential contaminants in the space atmosphere. For trace contaminant detection, the study considered gas chromatography, mass spectrometry, adsorption spectroscopy, infrared systems, interferometer techniques, microwave spectrometry, and molecular resonance techniques as potential methods. From the results of these investigations, gas chromatography and mass spectrometry seem the best potential candidate systems. The gas chromatography provides positive separation of elements into easily identifiable segments, thus assuring detection of the major contaminants. The major drawback of this system is its inability to detect trace contaminants not anticipated prior to flight. Mass spectrometry will identify all potential contaminants; however, the pattern is relatively difficult to analyze for all contaminants and many of the trace gases may be masked by larger quantities of other constituents with the same

5.12 (Continued)

molecular weight. The final spacecraft system may require a combination of the two for full safety precautions unless these individual shortcomings can be overcome.

In the area of oxygen partial pressure sensors, the present choice is the polarographic sensor. It represents a rugged, simple design which is presently available. Its major disadvantage is limited life. However, replacement sensors are lightweight and, in the cartridge form described by Beckman, are easily replaced. Carbon dioxide partial pressure monitoring will be accomplished with an infrared sensor which is felt to be the best approach of those currently being considered in industry.

The primary instrumentation concern for spacecraft operation is the water potability measurement. At present, no satisfactory state-of-the-art method exists for this criteria. The best available method found to date is use of a 24-hour culture to determine the type of bacteria present. This may be reduced to a somewhat shorter period with careful design and analysis of equipment. However, it is not felt that a period of hours is satisfactory for water potability determination. Work should be initiated on a method of continuous bacteriological checking of the water, since this is the area which is of prime concern.

Another potential solution, and the recommended method at this time, is heated storage of the drinking water. By subjecting the water to a sufficiently high temperature, one may eliminate most or all of harmful bacteria to be found in the water. It may not be desirable to depend completely on this method without considerable pre-flight ground testing. If, however, this method can be proved a suitable method, the development cost of a bacteriological sensor can be eliminated.

5.13 Hygiene

The hygiene study on the subsystem level was concerned with the functions of bathing, shaving, barbering, teeth cleaning, and waste collection. On a spacecraft, some aspects of hygiene are different from those on Earth due to the absence of extraneous dirt and the necessity for operating in zero "g".

Two basic methods of skin cleaning were considered: washing with soap and water and wiping with impregnated pads. For washing, a water shower system was proposed which utilized a heated, directed airflow to control and remove water, and provide drying. A hand washing device would be used where the hands would be inserted through flexible closures and the water spray would be turned on by a foot or knee switch. A plain simple soap such as Castile or a synthetic cleansing agent

5.13 (Continued)

such as Phisohex would be used with this skin cleaning method.

Impregnated pads contain the following major constituents: a cleansing agent, an oil or wax base substance to prevent skin dryness, a disinfectant, and alcohol to enhance drying of the applied materials. These pads are pre-packaged, opened and used one time and then reinserted in their original package for disposal.

These two methods were evaluated on the basis of system weight, reliability, atmospheric contamination by cleansing constituents, efficiency of cleaning, and psychological considerations. As a result of this evaluation, impregnated pads were chosen for the Excursion and Re-entry Modules and a water shower was selected for the Mission Module.

Shaving and barbering could be accomplished by an electric razor with an alternate head for clipping the scalp hair to a short length. The unit will also contain a small fan to draw hair particles into a receptacle. Barbering can be performed inside the space shower and be followed by a shower and shampoo to wash away any residual hair.

Nails will be cut with a conventional clipper which collects and retains clippings in a receptacle.

For the cleaning of teeth an edible toothpaste will be squeezed onto a brush and the teeth cleaned in a normal manner with care taken to keep the lips closed around the handle to prevent the escape of saliva and paste. Upon completion, the toothpaste will be swallowed and this can be followed by a drink of water.

Waste collection methods were evaluated primarily with respect to reliability and simplicity of operation. For urine collection there was a choice between units that make personal contact in order to provide sealing and those that do not make direct contact. Two units that fall into the latter category were considered. One was a centrifugal urinal developed by the Whirlpool Corporation. The primary objection to this was the uncertainty of complete collection at the end of the urination period. The other device was a funnel with an air stream section to control and direct the liquid in zero "g". The device finally selected was the simplest and most foolproof. It was a personal contact device consisting of a sealing head, a receptacle in the form of a flat rubber tube, and a roller clamp to remove the urine from the tube. Since positive contact is made, each crew member will have his individual collector.

5.13 (Continued)

Three different methods were considered for feces collection. One was a simple hand held bag as has been proposed for the Gemini missions. The objection to this method is the tiring and awkward position that must be maintained during defecation. This would be satisfactory for the ERM, however, due to its short mission time. For the long mission to and from Mars, the weight of these bags would be excessive (491 lbs). However, for the shorter three man mission in the MEM, the weight is only 23.4 lbs and this method would be acceptable.

Another method considered which would be more acceptable for use on extended missions would consist of a more conventional toilet seat utilizing a direct air blast to remove the feces in zero "g". A variation of this is to use a water wash and flush. The objections of this system are that a very close seat-anus seal is required to prevent the escape of water, and there are problems associated with the processing of the flush water.

It was felt that no entirely suitable system of feces collection has been described in the literature for long duration missions with the zero "g" problem (i.e., the MMM). This is one subsystem that requires extensive work to produce even prototype hardware.

For the MEM the presence of gravity simplifies the problem. Here a conventional type toilet was recommended. For the short zero "g" portion of the mission, hand held bags could be used for feces collection.

6.0 SYSTEM INTEGRATION SUMMARY

This section summarizes the selected subsystems, integration and operation of the environmental control and life support systems (EC/LSS) for the three modules of the Mars Landing and Reconnaissance Mission vehicle. Two EC/LS systems (System "A" and System "B") are presented for the Mars Mission Module since it was not possible to make a definite choice between these systems at this time.

6.1 Mars Mission Module - System A

6.1.1 General

This section summarizes the selection of subsystems and operation of the Mars Mission Module - System A. This section is intended as a summary only, and will not describe the system in detail. Additional detail on the Mars Mission Module System may be found in Section 3.0 of Volume 3 of this report.

It should be noted that this system is called "System A". The reason for this is that two different systems have been devised for the Mission Module; one using the solid adsorption - solid electrolyte method of CO_2 management, and another using the molten carbonate method. "System B", or the system using the molten carbonate method, will be described in Section 6.2. It was not possible to make a definite selection between these two systems at this time.

The following summary description will discuss the major functional circuits in the system and may be more clearly understood by referring to the system schematic, Figure 6-1, or, if more detail is desired, Figure 3-9 of Volume 3 of this report. The three flow circuits to be discussed will be (1) Cabin Atmosphere, (2) Water Reclamation, and (3) Heat Transport Fluid.

6.1.2 Cabin Atmosphere Flow Circuit

The Cabin Atmosphere flow circuit may be broken down into two basic loops: one for dehumidification and contaminant control, and another for sensible cooling. This arrangement was selected after a study in which several different arrangements were evaluated on the basis of total equivalent weight.

The humidity and contaminant control flow loop begins with air inlet ports from the cabin which contain screens to prevent large objects, which might be floating in zero "g", from entering the flow loop. From this point the air goes through a manual shutoff valve, which is closed to isolate the cabin during suit operation if the cabin has been punctured by a meteoroid or for any other reason is depressurized. The air then flows past the total pressure sensor which is used for displaying total

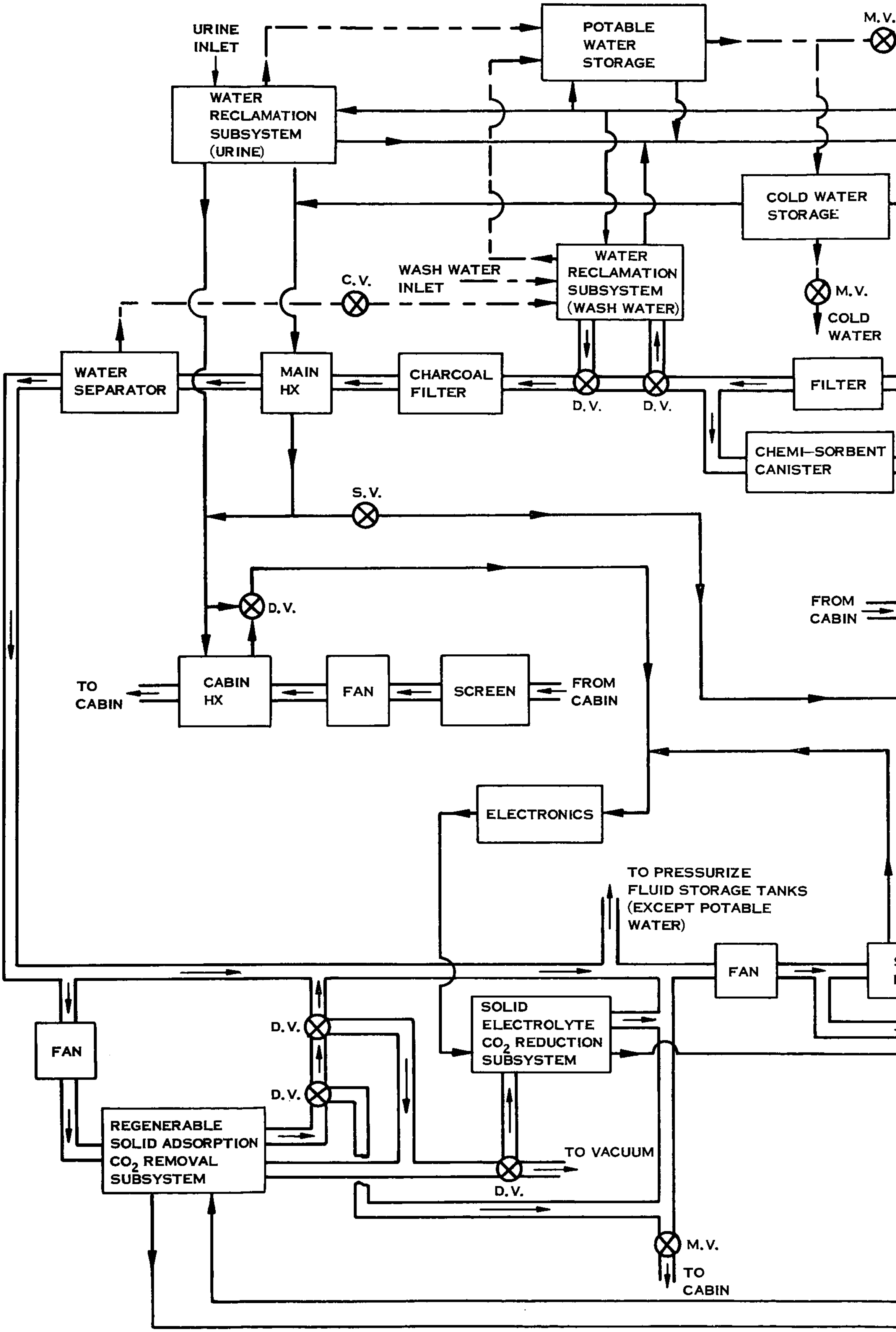
6.1.2 (Continued)

pressure on the instrument panel and a debris trap where free moisture droplets and large particles are removed from the stream. Next, the atmosphere flows through the redundant fans which circulate the flow in this loop.

From the fan, the atmosphere flows through the fine filter where any particulate matter which is generated either in the cabin or from any of the equipment is removed. Following the filter the atmosphere flows through a diverter valve and through the wash water reclamation system. In the event of a failure of the water reclamation system this valve can be turned to the opposite position allowing flow to go directly through the charcoal filter and on around the remainder of the humidity and contaminant control loop. During normal operation, however, the air flows through a heater where it is heated to about 160°F and then into the wash water evaporator where the wash water is evaporated into the air stream. This vaporization causes the combined stream temperature to drop to about 75°F. The combined stream then goes into another heater where it is heated to 160°F again. It then flows through another evaporator where more wash water is evaporated into the stream. The water vapor and air then goes through the charcoal filter where heavy molecule contaminants are removed from them. The activated charcoal bed is placed between the evaporator and condenser in order to serve the dual purpose of deodorizing the air stream and the wash water (which passes through it in vapor form). Some of the water will condense on the charcoal bed and thereby reduce its efficiency. However, the advantage of purifying both air and water with one charcoal bed outweighs this disadvantage. Next, it flows into the condensing heat exchanger. Here the air is cooled down to about 45°F resulting in condensation of most of the water contained in the air stream. This mixture of air and water droplets then flows through a diverter valve (which is in the system for the purpose of allowing switchover from one water separator to another in the event of failure in the primary separator) and into an air turbine driven rotary separator. Here the free moisture in the stream is removed and pumped into the water management system. From the separator, the air, now dehumidified, flows back to the cabin through another manual shutoff valve.

The contaminant control subsystem operates in a bypass loop which takes flow from the main flow stream just downstream of the filter, and returns it upstream of the fan.

After leaving the water separator, the flow splits, with roughly one-half going to the CO_2 removal and reduction system and the rest flowing on to the cabin. In this CO_2 removal system the air is thoroughly dried in the silica gel canisters to remove all moisture which would overload the zeolite beds. From here the air flows into the zeolite canisters which remove the CO_2 from the air. The CO_2 free air then flows



MARS MIS

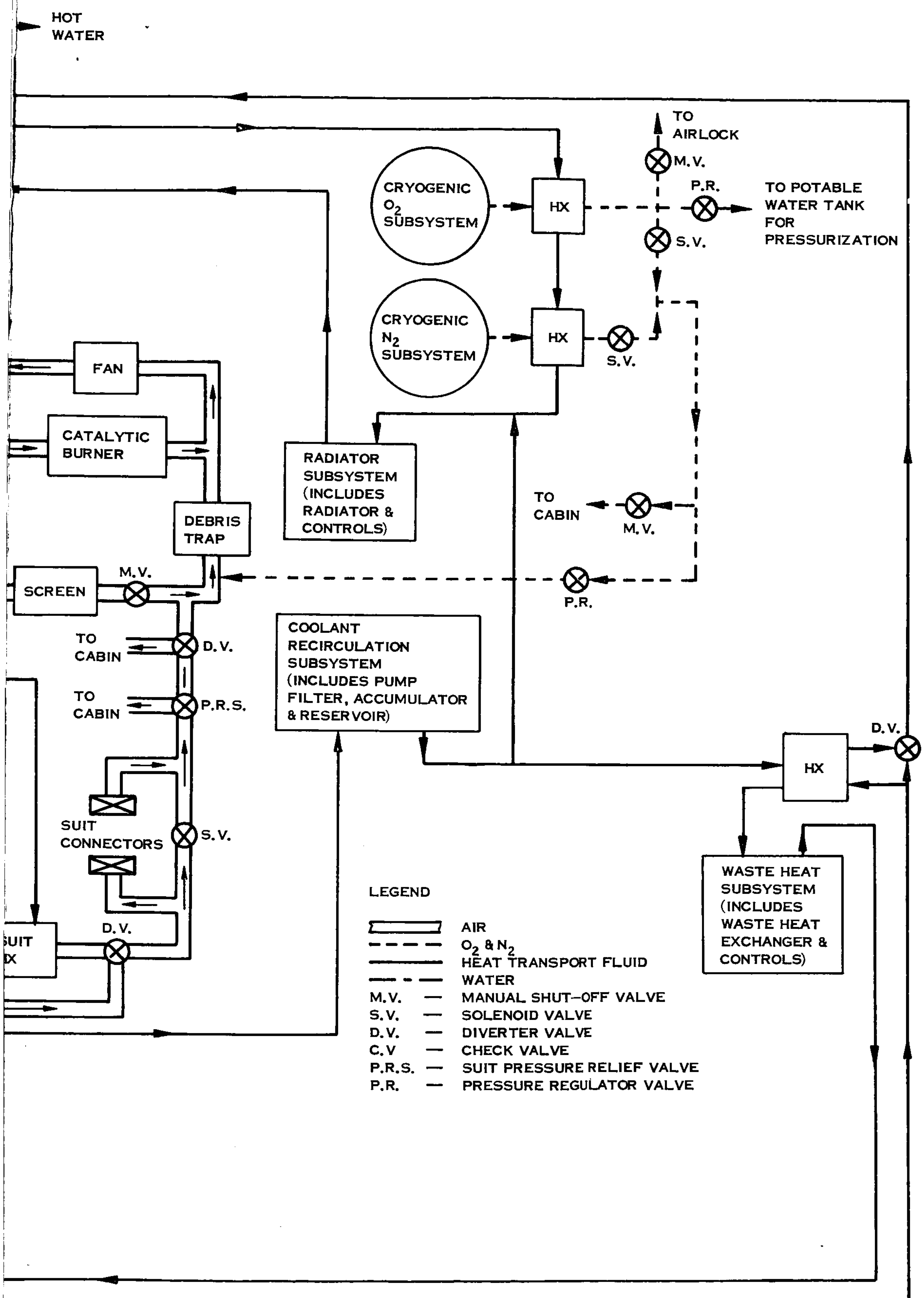
SYS

ENVIRONMENTAL CONTROL

SIMPLIFIE

1

FI



SION MODULE
TEM A
AND LIFE SUPPORT SYSTEM
D SCHEMATIC

URE 6 — 1

#2

6.1.2 (Continued)

out through a diverter valve and rejoins the remainder of the airflow back to the cabin. The CO_2 that was separated out in the zeolite bed is desorbed from the zeolite canister during another portion of the operating cycle and is sent to a CO_2 accumulator and then to the solid electrolyte CO_2 reduction system. The oxygen which is formed in the CO_2 reduction system rejoins the recirculating airstream just upstream of the point at which it flows back to the cabin. It will be noted that there is a separate suit circuit included on the schematic. During normal operation these fans are not operating and there is no flow through this circuit.

The atmospheric constituents for make-up of leakage and metabolic use are admitted to the cabin from the cryogenic (subcritical) storage system. The nitrogen required is simply that amount needed to make up for leakage, or roughly 0.05 lbs/hr. The oxygen required is that required for make-up of leakage, and that required to make up for the difference between metabolic O_2 intake and the amount recoverable from CO_2. The total required is .125 pounds per hour.

These gases normally are supplied directly into the cabin; however, a bypass is provided so that oxygen may be provided directly to the suits when suit operation becomes necessary. Under normal operation the atmospheric constituents are both supplied through the same total pressure regulator with an upstream selector valve determining whether O_2 or N_2 is supplied to the cabin, depending on the partial pressure of O_2 in the cabin at the time. This control takes advantage of the simplicity of self-powered inflow regulators to control total pressure. The total pressure regulators are redundant to allow operation in the most likely mode of failure (the open mode).

The second portion of the atmospheric conditioning circuit, is the cabin sensible cooling loop. This circuit contains redundant fans, which operate in the same manner as the main flow loop fans and check valves, and a plate and fin type heat exchanger. This circuit cools the cabin air from 75°F to 60°F. The outlet temperature was determined by the maximum dew point in the cabin, which was 56°F. A margin of four degrees above the dew point was provided to prevent condensation in the heat exchanger, The cabin temperature control consists of a cabin heat exchanger coolant inlet temperature control and a modulating cabin heat exchanger coolant bypass valve. The coolant inlet temperature control is of the mixing type. The proportion of hot and cold fluid is varied by modulating flow through a loop parallel to the cabin heat exchanger.

Figure 6-2 represents the design point case of the air loop. Air leaves the cabin and enters the main loop at a temperature of 75°F and a relative humidity of 50%. It

MARS MISSION MODULE
CABIN ATMOSPHERE LOOP
DESIGN CASE

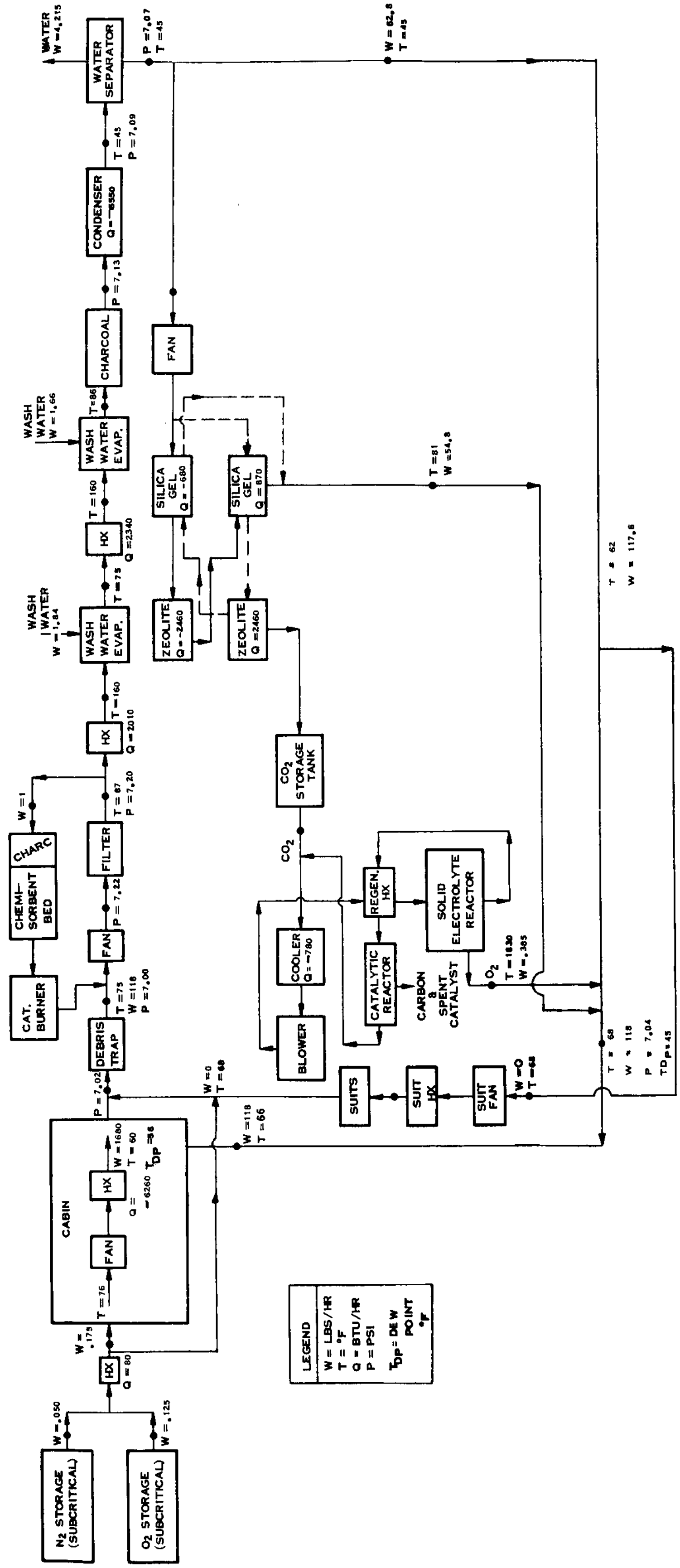


FIGURE 6 — 2

6.1.2 (Continued)

then passes through the humidity and contaminant control loop and returns to the cabin at a dry bulb temperature of 66°F and a dew point of 45°F. The cabin sensible cooler processes 1680 pounds per hour of cabin atmosphere from 75°F down to 60°F.

6.1.3 Water Reclamation Circuit

The water flow circuit is divided into two sections, the urine system and the wash water system. It was considered advisable to treat the two separately since this allows separation of the contaminated urine from the relatively uncontaminated wash water so that a failure in one system does not result in contaminating the entire water supply. A flow chart of this circuit is shown in Figure 6-3.

The system selected for urine processing is a closed loop air evaporation system. Urine is collected from the urine collection device and placed in a processing tank where it is mixed with a pretreatment chemical which fixes the urea, preventing it from breaking down, and also kills any bacteria which may be in the urine. This is done on a batch basis,adding the required amount of chemical to a full tank of urine by means of a manual chemical injector. During the time when the urine process tank is being filled it is isolated from the remainder of the system by a shutoff valve. After the chemical has been added this valve is then opened and the urine is forced into the accumulator. The shutoff valve is closed again and the urine discharge from the urine collector goes into the processing tank.

From this point the accumulator feeds urine through a feed control valve into the evaporator at a rate sufficient to keep the evaporator wick saturated. An on-off process has been chosen to supply fluid to the wick. This system depends upon measuring the degree of saturation of the wick. When the wick achieves a predetermined dryness, the inflow valve is actuated and fluid is delivered to the wick. When the sensor indicates that the wick is again wet, the inflow is closed off.

Recirculating air is heated in the urine-to-air pre-heater to about 140°F and is then used to evaporate the water from the urine in the evaporator. This vapor is then filtered through a charcoal filter to remove odors after which it flows into the urine condenser where the urine vapor is condensed from the air. The mixture of air and free water droplets then passes into the water separator where the condensate is removed from the air stream. The air passes through the fan and back to the urine-to-air heater to be circulated through the loop again, while the water flows through a charcoal filter, an ultraviolet light for killing any remaining bacteria, and into the hold tank. The potable water storage tank is held at a temperature of 140° to 160°F, for the purpose of killing most of the bacteria which might be remaining in the water

MARS MISSION MODULE
WATER RECLAMATION SYSTEM
DESIGN CASE

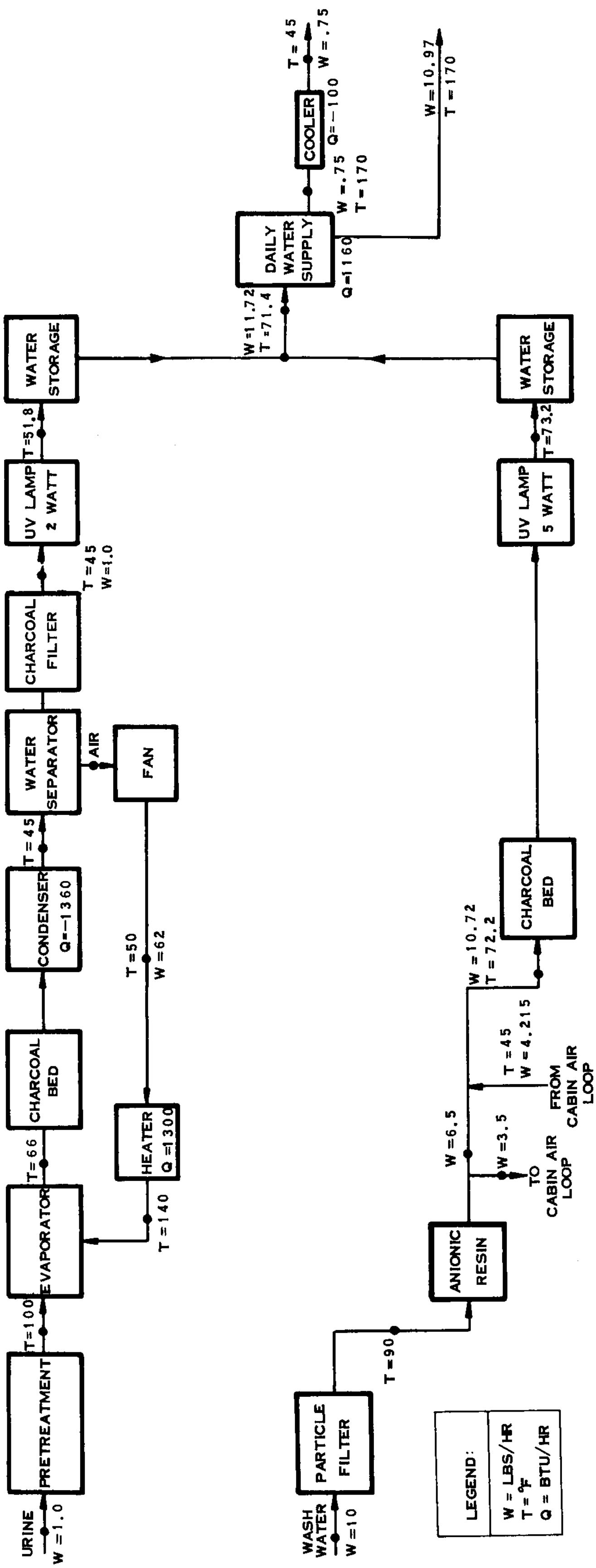


FIGURE 6 — 3

6.1.3 (Continued)

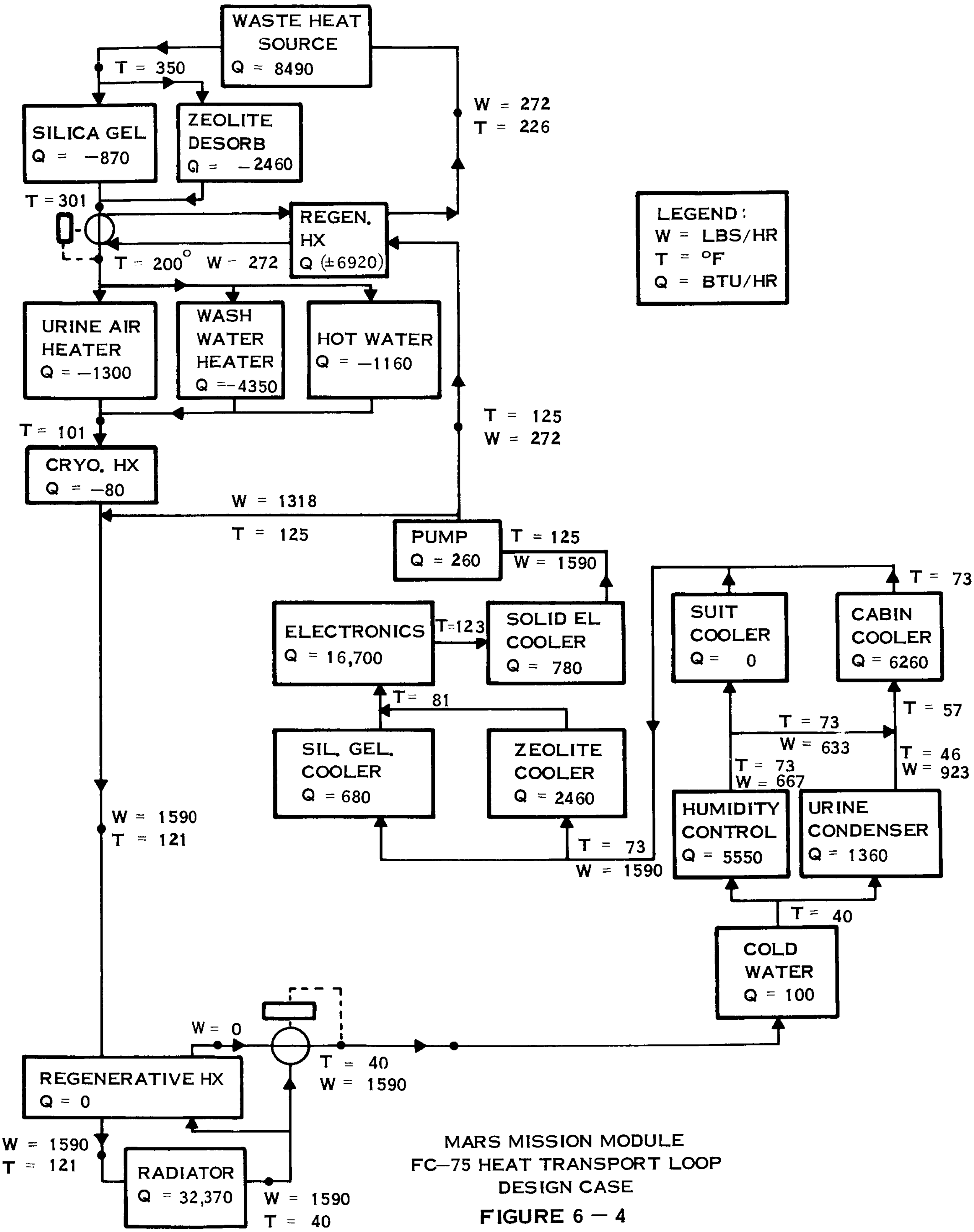
and also preventing the growth of new bacteria. From the potable water storage tank, hot water which is desired for cooking or any other purpose is drawn through the hot water dispenser. Cold water is tapped off from this same hot water line, but flows through the cold water heat exchanger where it is cooled prior to being discharged through the cold water dispenser.

The other portion of the water management system is the wash water reclamation system which has been discussed previously under the cabin atmosphere loop. Some of the points not covered in that discussion will be covered here. The used wash water is brought from the shower or wash cabinet to the open loop air evaporation system. It flows into the filter which removes particulate matter and then into the anionic resin chamber where the soap is removed. From this point it goes into an accumulator from which it is fed to the wash water reclamation system. The feed control for this device is the same as that described under the urine air evaporation system. In this system 40 pounds per day per man is used for the total washing requirements. However, only 14 pounds per man day is processed through the open air loop evaporation system. The water flows through the feed control valves into the two evaporators and is evaporated into the cabin air stream at which point it joins with the humidity water from the cabin loop. The remainder of the wash water which is not fed to the open air loop evaporation system flows directly through a charcoal filter and into the wash water and humidity water hold tank. The flow which was processed by the air evaporation system joins with this stream just upstream of the charcoal filter and also flows into the hold tank. The water is held in this tank for a period of time sufficient to take a test to determine the water potability. If the water tests potable, it is put into the potable water storage tank. If the test indicates that it is not potable, it can be returned to the accumulator and reprocessed after the malfunction of the process system has been found and corrected.

6.1.4 Heat Transport Fluid Circuit

This circuit is used to transport heat from the various heat exchangers and components in the spacecraft which require cooling, to the space radiator to be rejected to deep space, and to carry the heat from the waste heat source (nuclear power source) to the items in the system which require heating. To make the best use of the waste heat for all sources within the system, and keep the load on the space radiator to a minimum, the heat transport system was arranged as shown in Figure 6-4.

The fluid leaves the radiator at a controlled temperature of 40°F minimum and circulates through all the items to be cooled, then to the waste heat source where the fluid is heated to a controlled 350°F, then to the items to be heated, and finally



MARS MISSION MODULE
FC–75 HEAT TRANSPORT LOOP
DESIGN CASE
FIGURE 6 — 4

6.1.4 (Continued)

back to the space radiator for cooling. As previously mentioned, the heat transport fluid selected was FC-75. This fluid provides the lowest pumping power to heat transfer ratio, has a very low freezing point, and can be operated at temperatures in excess of 700°F without danger of breakdown.

Review of the heat transport loop will start with the fluid at the outlet of the radiator. The radiator has been designed to provide 40°F at this point with the maximum load on the radiator during the period of maximum solar influx. Therefore, during periods of lower heat load on the radiator and no solar influx the discharge temperature could drop as low as 2°F. Since this could result in freezing of water in the various heat exchangers, a temperature control and regenerative heat exchanger have been added to control the fluid temperature leaving the radiator to 40°F. In this case and all other cases where control is needed in the glycol system, the system has been devised to allow simple, self-powered mechanical temperature control.

The FC-75 flow rate in this cooling loop was sized to handle the entire cooling load without exceeding 72°F discharge temperature from the cabin cooler. This can be done with a cabin cooler effectiveness of 83%. Using these criteria, the flow rate was set at 1590 pounds per hour. This fluid leaves the radiator at 40°F and flows to the water cooler where water for drinking is cooled. From this point it flows in parallel paths to the urine condenser and to the main loop condensing heat exchanger. Flow from the urine condenser then rejoins the flow from the main loop condensing heat exchanger, and the combined fluid flows into the cabin heat exchanger through a temperature control system. This temperature control keeps the fluid inlet temperature at a minimum of 57°F to prevent moisture from condensing in that heat exchanger. From this point, the FC-75 flows to the CO_2 removal system where it is used to remove the heat generated by the adsorption of moisture by the silica gel bed. It also flows to the zeolite beds where the heat of adsorption of CO_2 is removed. The fluid then flows through the electronics where it removes the heat from the electronics equipment, and then into the solid electrolyte cooler where the excess heat is removed from the CO_2 reducing apparatus. The discharge temperature from the electronics with the 1590 pounds per hour flow and all the electronics operating is 123°F, which is in the allowable range. From the solid electrolyte cooler the fluid flows through a filter and into the recirculating pumps. At this point the fluid has cooled all the items which require cooling and is at the highest temperature it will attain by removing heat from items in the spacecraft. However, this temperature is not adequate to desorb the CO_2 removal canisters. Therefore, it is necessary to heat the fluid in the waste-heat exchanger.

Fluid for heating the zeolite must be supplied at 350°F and must be at a minimum of 300°F leaving the bed. Therefore, to provide the required heat in this temperature range, the flow through the beds must be at least 272 pounds per hour. Since

6.1.4 (Continued)

this is all the flow that is required, the remaining flow is bypassed and sent to the radiator circuit. The temperature of the 350°F FC-75 stream is controlled by a bypass valve operating in the Dowtherm stream which transports the heat from the nuclear reactor.

The fluid leaving the silica gel and zeolite beds mixes and then can be used for heating of the air (in both the wash water air heater and the urine air heater) and the water (in the potable water storage tank). However, this fluid is required at a maximum of 200°F, and the temperature of the fluid at this point is 301°F. Therefore, a regenerative heat exchanger and temperature control have been added to decrease this temperature and reduce the amount of waste heat required by preheating the fluid to the waste heat exchanger. The operation of this temperature control is identical to that of the radiator discharge temperature control.

The remaining heat in the heat transport fluid at this point is used to warm the make-up oxygen and nitrogen from the cryogenic source so it will enter the cabin at room temperature. This is particularly important during repressurization and suit purge when large quantities of oxygen are used. This heating is done in the cryogenic heat exchangers just upstream of the point where the fluid returns to the radiator system.

The method of heat rejection selected for the Mission Module is a space radiator. Selection of the radiator for this module was dictated by the heat load to be dissipated, and the area available on the spacecraft. Studies were performed to determine the optimum tube spacing and method of meteoroid protection to result in the minimum weight radiator which could be made to fit within the area available. The resulting radiator requires 22 tubes which are 30 feet long and spaced at a distance of 15 inches. Two basic types of meteoroid protection were studied for this radiator. The first is the heavy tube protection which was evaluated using the Bjork penetration criteria, and the multi-sheet protection which was evaluated using the Charter's-Summer's penetration criteria. The reliability can be increased considerably by using several extra tubes, with valves to isolate a panel in the event of a puncture. By using this extra panel and multi-sheet meteoroid protection, a no puncture probability of better than .9999 can be attained for a total weight of about 100 pounds.

6.1.5 Weight and Power Summary

Table 6-1 presents a weight and power summary of the various subsystems included in the MMM Environmental Control and Life Support System (EC/LSS).

TABLE 6-1

MMM - EC/LSS - SYSTEM A

WEIGHT AND POWER SUMMARY

Subsystem	Average Power Watts	Dry Weight Lbs.	Fluid and Expendable Weight Lbs.	Total Equivalent Weight Lbs.
Ventilation	390	276.0	180.6	651.6
Heat Transport Fluid	75	43.9	120.0	201.4
CO_2 Management	1,520	487.8	29.0	1,276.8
Water Management	40	102.3	406.3	528.6
Atmospheric Supply		317.7	1,741.0	2,058.7
Miscellaneous*		380.8		380.8
Space Radiator		105.0		105.0
Spares		341.1		341.7
System Total	2,025	2,054.6	2,476.9	5,544.6

* Includes Control Panel, Hygiene Equipment, Feces Processor, Ducting, Clamps, Brackets and Mounting.

6.2 Mars Mission Module - System B

6.2.1 General

This section summarizes the selection of subsystems and the operation of the Mars Mission Module Environmental Control and Life Support System - System B. This section is intended as a brief summary only and will not describe the system in detail. Additional detail may be found in Section 3.4 of Volume 3 of the Report.

In the design of an ECLS system it is necessary to consider the full range of operating conditions from the combination of highest heat load and most difficult heat rejection conditions to the minimum heat load and the best performance conditions for the heat rejection system. Several of these extremes have been considered and are reported in Volume 3 of this Report. This summary section will consider only the maximum load under normal operating conditions, namely:

1. Six man crew.
2. Average metabolic heat load.
3. Maximum solar heat load.
4. All electronic equipment operating.
5. Water processing equipment operating at normal rate.

This case has been termed "Design Case".

As previously stated, the primary difference between systems A and B is the method of CO_2 management utilized. This section describes the integration of a system incorporating the molten carbonate subsystem for removal and reduction of CO_2. The main difference between systems which use a molten carbonate CO_2 management scheme as opposed to the solid adsorption-solid electrolyte technique results from the requirement for a high temperature source of heat for the desorption of the solid adsorbent material. In System A, this high temperature required the use of waste heat from the power source. Once required for one application, this heat could be used in the water processing heaters and for maintaining temperature in the potable water storage tank. The molten carbonate system presents the alternatives of either using waste heat to minimize the size of the water processing units and supply water heat, or taking a fixed weight penalty on water processing equipment and supplying water heat from some auxiliary source such as isotope heaters or electric heaters.

The alternative of either using waste heat or not in developing a system about the molten carbonate scheme has a direct effect on the integration of water processing with the cabin atmosphere flow loops, sizing of the radiator system, and technique of controlling temperatures in the coolant loop. As a result, two systems, with

6.2.1 (Continued)

and without waste heat, had to be evaluated to the point of total equivalent weight penalty in order to make a decision between the two. In actual practice, only the difference between non-common components was compared. The results of this study indicated that the system without waste heat was about 25 pounds lighter than that using waste heat. Since it is also a simpler system with few potential reliability and maintenance problems, the system which does not utilize waste heat from the power source was selected.

The discussion in this section will describe the major functional circuits in the system and may be more clearly understood by referring to the simplified system schematic, Figure 6-5, or, if more detail is desired, Figure 3-27 of Volume 3 of this report. The major function circuits to be discussed are: 1) Cabin Atmosphere Loop, 2) Water Reclamation Loop, 3) Heat Transport Fluid Loop.

6.2.2 Cabin Atmosphere Flow Loop

The functions of the atmospheric flow loop may be broadly classified into four major categories; temperature control, humidity control, minor contaminant control, and possible integration of contaminated water processing. For each of the four functions a number of possible combinations of flow loops were evaluated before a final selection was made.

The arrangement finally selected consists of a main air flow loop which performs contaminant control, humidity control, and includes the urine water processing function, and a secondary cabin loop which performs only sensible temperature control and cabin circulation. This arrangement was chosen because it has the lowest equivalent weight penalty of any of the schemes considered, and it provides good temperature and humidity control while at the same time never allowing the dew point anywhere in the system to exceed 56°F. This precludes the possibility of condensation on the cabin walls. The inclusion of the urine processing function in the main air loop can be justified by recent studies which indicate that there is essentially no breakdown of the urine, after proper chemical treatment, if processing temperature is kept below 140°F. In this system the maximum temperature is below 120°F, providing more than adequate margin against breakdown.

The humidity and contaminant control flow loop begins with air inlet ports from the cabin. From this point the air flows through a manual shutoff valve which is closed to isolate the cabin during suit operation if the cabin has taken a meteorite puncture or for any other reason is depressurized. The air then flows past the total pressure sensor which is used for displaying cabin total pressure on the instrument panel.

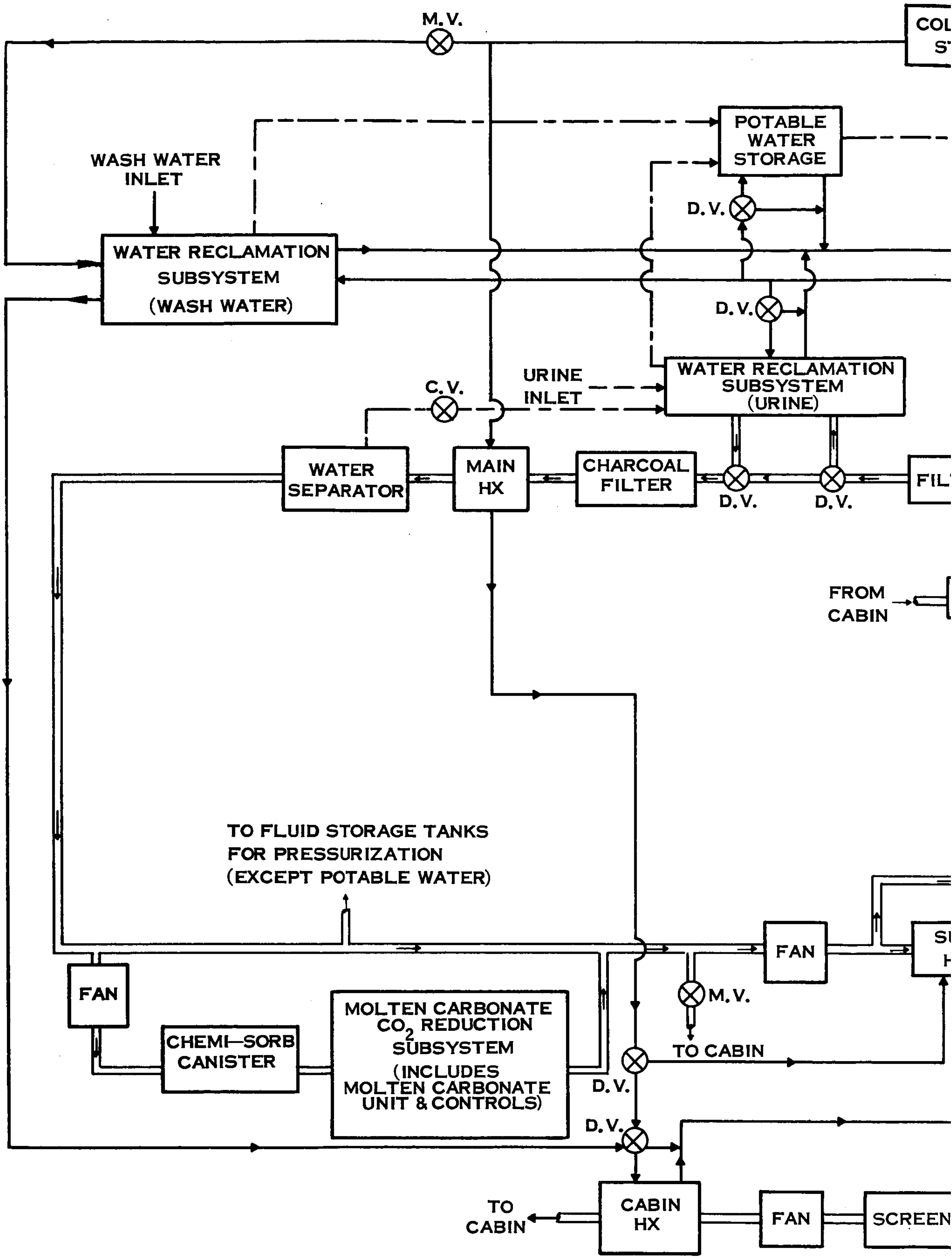
6.2.2 (Continued)

The air then flows through a debris trap where free moisture droplets and large particles are removed from the stream. Next, the atmosphere flows through the redundant fan and check valve combination which circulate the flow in this loop.

From the fan, the atmosphere flows through the fine filter which removes the particulate matter generated either in the cabin or from any of the equipment. Following the filter, the atmosphere flows through the diverter valve and through the urine water reclamation system. In the event of a failure of the water reclamation system, this valve can be turned to the opposite position, allowing flow to go directly through the charcoal filter and on around the remainder of the humidity and contaminant control loop. During normal operation, however, the air flows through a heater where it is heated to 95°F and then to the evaporator which is fed with pretreated urine. In the evaporator the air is cooled to 64°F. In emergency cases where additional water has to be processed, the heater outlet temperature can be raised to 110°F. This will result in an increase of evaporator outlet temperature to 67°F and an increased water processing rate of 40 percent. The combination of water vapor and air then goes through the charcoal filter where heavy molecule contaminants are removed. The activated charcoal bed is placed between the evaporator and condenser in order to serve the dual purpose of deodorizing the air stream and the water (which passes through it in vapor form). Some of the water will condense on the charcoal bed and thereby reduce its efficiency. However, the advantage of purifying both air and water with one charcoal bed outweighs this disadvantage. The feasibility of this approach has been confirmed by laboratory testing. Next, it flows into the condensing heat exchanger. Here the air is cooled to about 45°F, resulting in condensation of most of the water contained in the air stream. The mixture of air and water droplets then flows through a diverter valve which is in the system for the purpose of allowing switchover from one water separator to another in the event of failure in the primary separator, and into an air turbine driven rotary water separator. Here the free moisture in the stream is removed and pumped into the water management system. From the separator the air, now dehumidified, flows back to the cabin through another manual shutoff valve.

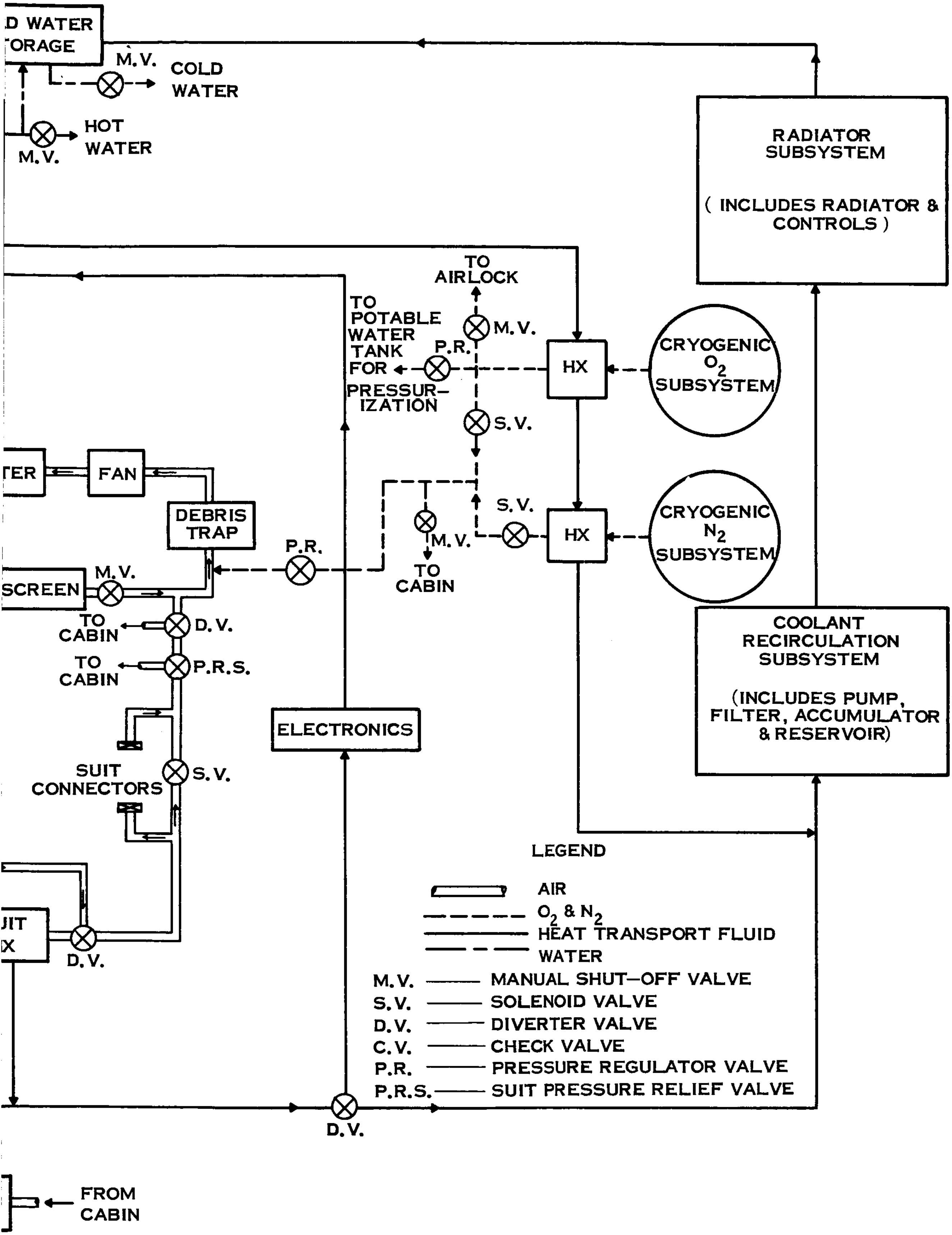
The carbon dioxide and minor contaminant control loop is located in a bypass loop which takes flow from the main stream just downstream of the water separators and returns the flow just downstream of the pick-up point.

The flow from the main loop passes through the fan to the chemisorbent bed for removal of materials which are not captured by the charcoal and cannot be burned. The stream then passes through a regenerative heat exchanger where it is preheated prior to entering the molten carbonate cell. In the molten carbonate cell the carbon dioxide in the air is reduced to carbon and oxygen. The carbon formed in this process plates out on an electrode and the oxygen is directly liberated into the air stream passing through the cell. Early test experience with this system showed



MARS MISSION
SYSTEM
ENVIRONMENTAL CONTROL AN
SIMPLIFIED S

FIGURE



MODULE
B
LIFE SUPPORT SYSTEM
HEMATIC

2

6.2.2 (Continued)

problems with absorption and reduction of water vapor. New melt compositions seem to have solved this problem but the location of this subsystem was chosen to minimize the possibility of this problem occurring. From the molten carbonate cell the very hot air passes through a catalyst bed where any contaminants which have not been removed up to this time, such as hydrogen and methane, are burned. Temperature control in the molten carbonate cell is achieved by bypassing a portion of the hot flow around the regenerator and thus cooling the cell inlet stream. This bypass must be sized to pass a large amount of flow during suit operation when there is no cooling of the cell.

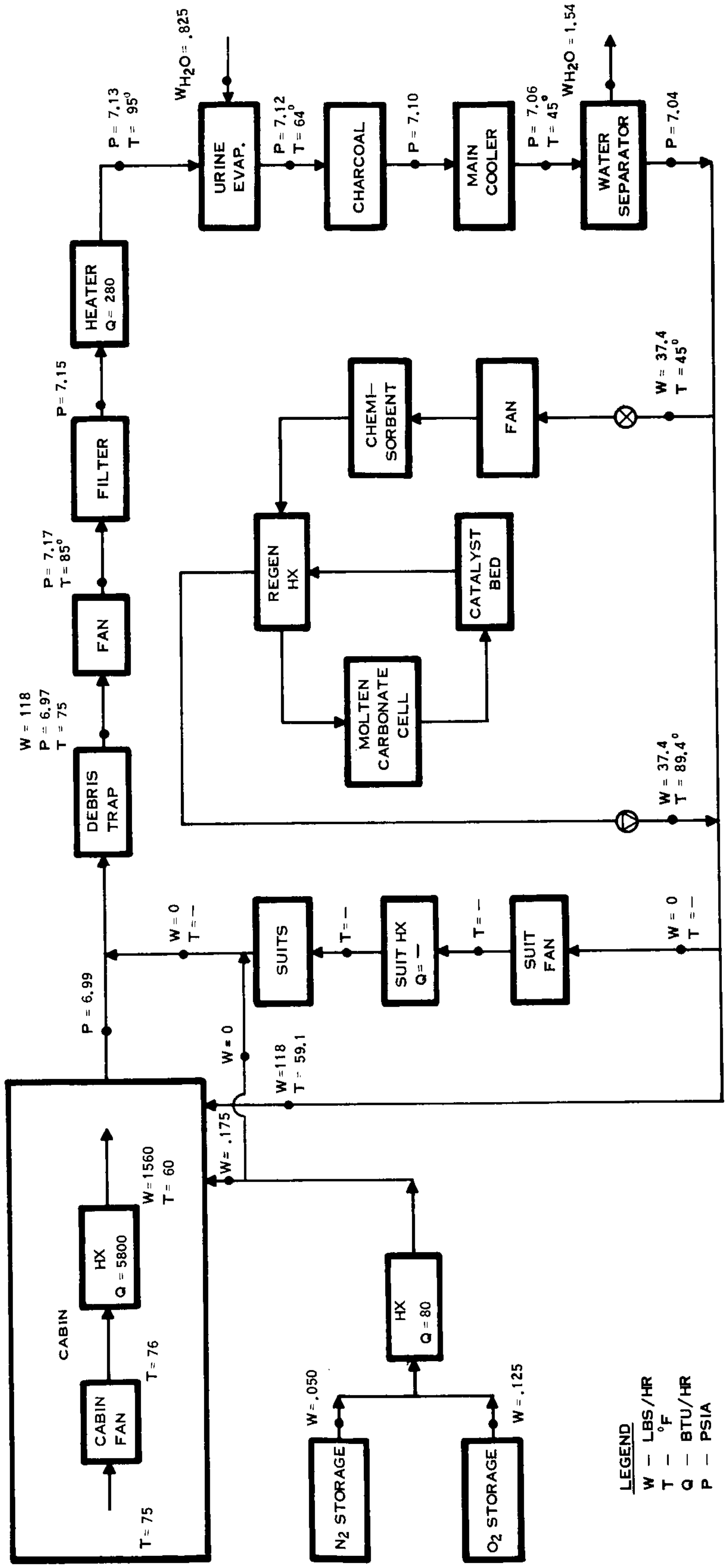
At the present time the molten carbonate process is in early stages of development. As a result the proposed equipment exists only as preliminary concepts whose reliability appears to be low. Further, the equipment would require some start-up time. It is felt that future work will solve the reliability and start-up problems and that this machine can be competitive with other concepts in this regard.

The location of the chemisorbent bed and catalyst in this schematic is somewhat different than the normally seen bypass loop around the main fan. However, the larger flows passing through the components will have a small penalty as these are low pressure drop items in a system with a fan motor of good efficiency. Further, this location will eliminate the requirement of heaters in the catalyst bed as the flow from the molten carbonate is sufficiently hot. The main advantage of placing these components in this location is the lower contaminant level achieved because of the larger flows. This is especially desirable with the open loop urine water reclamation scheme chosen for this system. Another advantage is quicker reduction in contaminant level in an event of illness, small fire, or electrical short. It is not expected that the amount of expendables will increase because this quantity is primarily dependent on total contamination removal which should not change.

It will be noted that there is a separate suit circuit included on the schematic. During normal operation these fans are not operating and there is no flow through this circuit.

The atmospheric constituents for make up of leakage and for metabolic consumption are admitted to the cabin from the cryogenic (subcritical) storage system. The nitrogen required is simply that amount needed to make up for leakage, or roughly 0.05 lbs/hr. The oxygen required is that required for make up of leakage, and that required to make up for the difference between metabolic O_2 intake and the amount recoverable from CO_2. The total required is 0.125 pounds per hour.

These gases normally are injected into the cabin; however, a bypass is provided so that oxygen may be provided directly to the suits when suit operation becomes necessary. Under normal operation the atmospheric constituents are both supplied through the same total pressure regulator with an upstream selector valve deter-



MARS MISSION MODULE
CABIN ATMOSPHERE CIRCUIT
DESIGN CASE

FIGURE 6 – 6

6.2.2 (Continued)

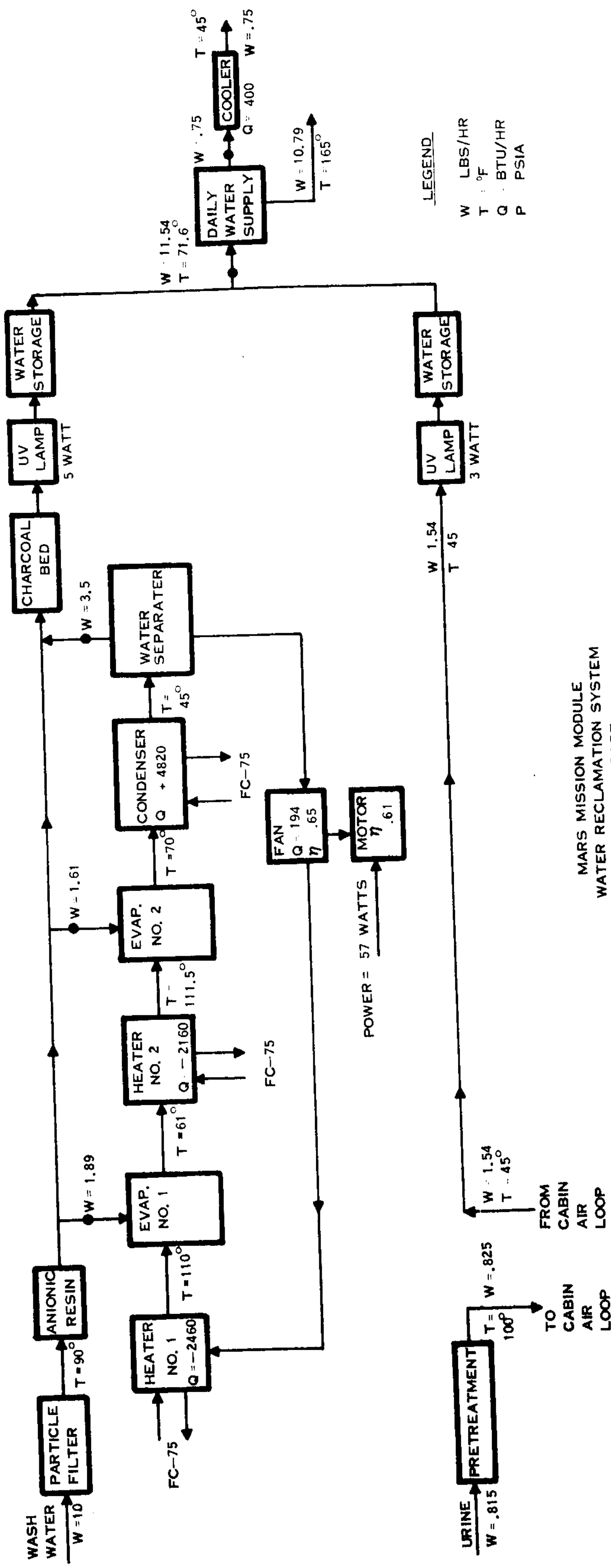
mining whether O_2 or N_2 is supplied to the cabin. This control takes advantage of the simplicity of self-powered inflow regulators to control total pressure. The total pressure regulators are redundant to allow operation in the most likely mode of failure (the open mode).

The second portion of the atmospheric conditioning circuit is the cabin sensible cooling loop. This circuit contains redundant fans, which operate in the same manner as the main flow loop fans and check valves, and a plate and fin type heat exchanger. This circuit cools the cabin air from 75°F to 60°F. The outlet temperature was determined by the maximum dew point in the cabin, which was 56°F. A margin of four degrees above the dew point was provided to prevent condensation in the heat exchanger. Additional assurance results from the fact that even with a full cabin heat exchanger load, the coolant temperature should be no lower than the dew point, and thus, there should not even be condensation on the walls of the heat exchanger. The cabin temperature control consists of a cabin heat exchanger coolant inlet temperature control and a modulating cabin heat exchanger coolant bypass valve. The coolant inlet temperature control is of the mixing type. The proportion of hot and cold fluid is varied by modulating flow through a loop parallel to the cabin heat exchanger to provide a constant temperature into the cabin heat exchanger.

Figure 6-6 represents the design point case of the air loop. Air leaves the cabin and enters the main loop at a temperature of 75°F and a relative humidity of 50%. It then passes through the humidity and contaminant control loop and returns to the cabin at a dry bulb temperature of 59°F and a dew point of 45°F. The cabin heat exchanger cools 1560 pounds per hour of cabin atmosphere from 75°F down to 60°F.

6.2.3 Water Reclamation System

The water flow circuit is divided into two sections; the urine system and the wash water system. It was considered advisable to treat the two separately since this allows separation of the contaminated urine from the relatively uncontaminated wash water so that a failure in one system does not result in contaminating the entire water supply. Also, to provide increased flow in the event that a failure occurred in one of the water processing systems, the urine loop was oversized in water handling capacity in both Systems A and B. In System A, the urine loop was of the closed type and handled 1 lb./hr. It normally operates for approximately 20 hours per day. Under emergency conditions it can be operated continuously. In System B the urine loop is of the open type and has an average flow of 0.815 lbs./hr. Under normal operation the loop is continuously processing the urine (24 hrs./day). For emergency operation, the flow of the heat transport fluid to the urine air heaters can be increased, thereby increasing the urine processing rate to its maximum value (1.16 lbs./hr.). A flow chart of this circuit is shown in Figure 6-7.



MARS MISSION MODULE
WATER RECLAMATION SYSTEM
DESIGN CASE
FIGURE 6-7

6.2.3 (Continued)

The system for reclaiming water from urine is an open loop air evaporation system. The urine is collected from the urine collection device and placed in a processing tank where it is mixed with a pretreatment chemical which kills any bacteria and fixes the urea preventing it from breaking down. After the chemical has been added the urine is forced into the accumulator. From this point, the accumulator feeds urine through the feed control valve into the evaporator at a rate sufficient to keep the evaporator wick saturated. An on-off process has been chosen to supply fluid to the wick. This system depends upon measuring the degree of saturation of the wick. When the wick achieves a predetermined dryness, the inflow valve is actuated and fluid is delivered to the wick. When the sensor indicates that the wick is again wet, the inflow is closed off.

The condensed respiration and vaporized urine water from the main loop heat exchanger are removed from the air stream in the water separator. After leaving the water separator, the water passes over a probe where the conductivity of the water is continuously monitored. If the conductivity rises above some prescribed value this is an indication of a system malfunction and the water is automatically returned to the accumulator by a diverter valve. A warning light on the control panel indicates the failure and thus the need for corrective maintenance by the crew. During normal operation the water passes through a charcoal filter, an ultraviolet lamp, and into the hold tank. Final water potability tests are made while the water is in the hold tank. From this tank, the water is transferred either to the potable water tank, if it is good, or back to the accumulator for reprocessing if it is not good.

The used wash water is brought from the shower or wash cabinet to a closed loop air evaporation water reclamation system. It flows into a filter which removes particulate matter and then into the anionic resin chamber where the soap is removed. From this point it goes into an accumulator from which it is fed to the wash water reclamation system. The feed control for this device is the same as that described under the urine air evaporation system. In this system, 40 pounds per man day is used for the total washing requirements. However, only 14 pounds per man day is processed through the air evaporation system. The water flows through the feed control valve into the two evaporators and is evaporated into the air stream.

In the air loop portion of this system, the air leaves the fan at 51°F and is directed to a heater where it is heated to 110°F by the heat transport fluid coming from the electronics. This flow which now has a low relative humidity goes to an evaporator where it becomes saturated with water vapor, leaving the salts behind in the wicking material. The air then goes through one more stage of heating and evaporation

6.2.3 (Continued)

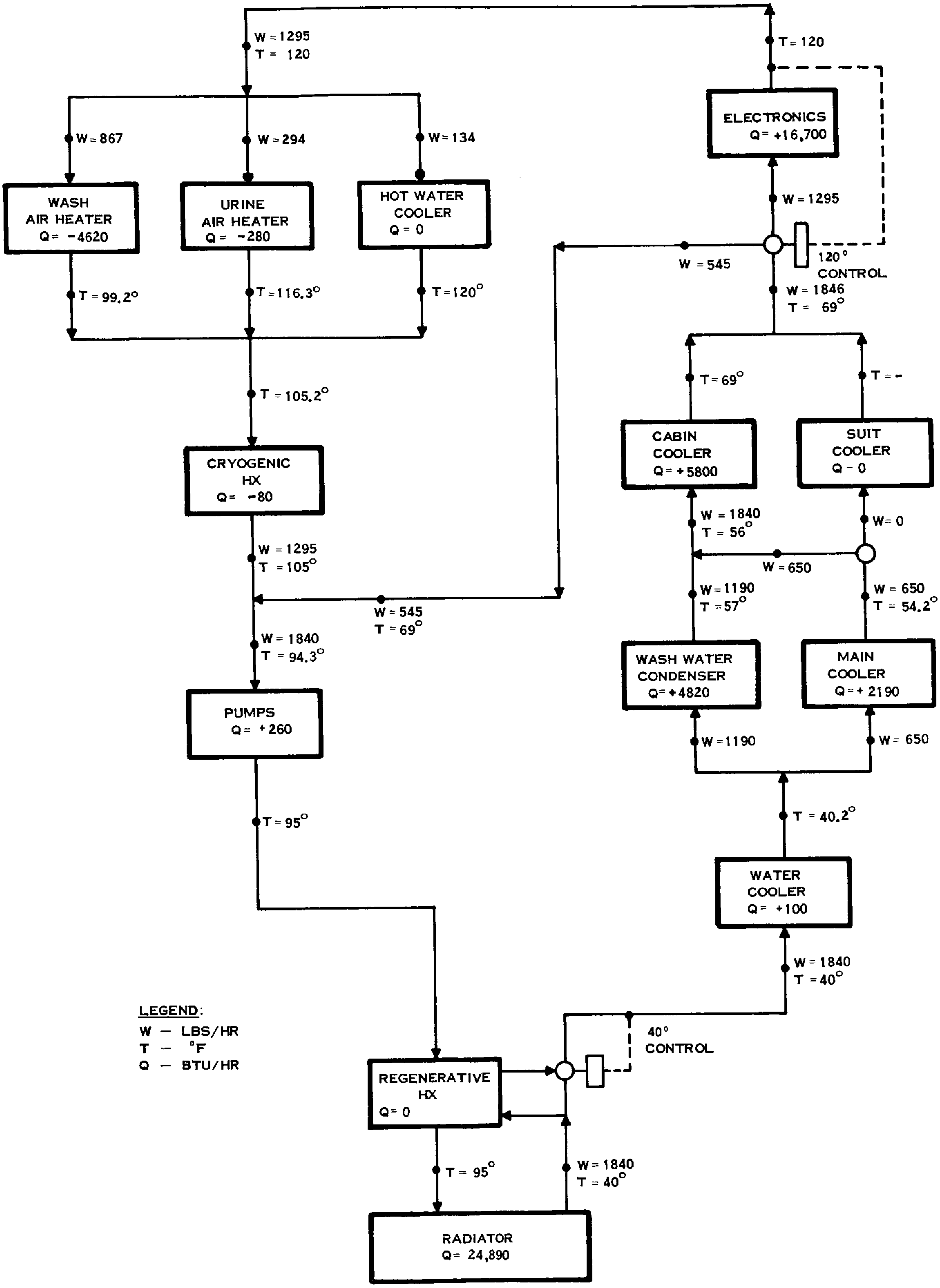
before passing through a charcoal bed and on to the wash water condenser. In the condenser, the now saturated air stream is cooled to 45°F and the water picked up in the evaporators is condensed. This mixture of saturated air at 45°F and free water is divided in the water separator. Downstream of the water separator the air returns to the fan and the water rejoins the wash water which bypassed the air evaporation loop. This combined water stream then passes over a conductivity probe as did the urine and respiration water in the other loop. If at this point the conductivity is too high, it is returned to the filter and a warning light informs the crew of the malfunction. If the water passes the conductivity test it flows through a charcoal filter, past an ultraviolet lamp, and into the hold tank. If the water fails the final potability test in the hold tank, it is returned for reprocessing. If potable, it is transferred to the main potable water tank. In the event that the wash water accumulator becomes overfilled due to a large flow surge or a lot of contaminated water, provision is made to transfer some of the excess water to the urine water processing system which has the capability of processing a greater than normal amount of flow.

The potable water storage tank is held at a temperature of 140-160°F for the purpose of killing most of the bacteria which might be remaining in the water and also preventing the growth of new bacteria. From the potable water storage tank hot water which is desired for cooking or for any other purpose, comes through the hot water discharge. Cold water is tapped off of the same hot water line, but flows through the cold water heat exchanger where it is cooled by the cold FC-75 and then through the cold water discharge.

6.2.4 Heat Transport Fluid Loop

The function of the heat transport fluid is to serve either as a heat source or sink for the heat exchangers and cold plates in the module and then to dissipate the heat through the space radiator. In order to minimize the system penalty an optimum arrangement of heat transfer components must be determined for each system considered. The configuration chosen for this system is shown in Figure 6-8.

The temperature leaving the radiator will vary with the heat load on it. The design point for the radiator is a 40°F outlet temperature under the maximum normal load condition. The outlet temperature of this radiator may drop to as low as 3°F under the minimum heat load case and even lower under some emergency conditions. In order to prevent large temperature fluctuations in the system components with changes in the radiator load and to prevent freezing of water in the systm, a regenerative heat exchanger and temperature control were added to the system to supply coolant to the loop at a constant temperature of 40°F.



MARS MISSION MODULE
HEAT TRANSPORT CIRCUIT
DESIGN CASE

FIGURE 6 – 8

6.2.4 (Continued)

The operation of the regenerative heat exchanger - radiator combination depends on the fact that with constant coolant flow the temperature change in the coolant across the radiator is only a function of heat load. Further, the temperature level in the radiator will seek the level at which radiator loss will equal the output of the coolant system. In order to hold the temperature level in the coolant system at 40°F or above, the radiator average temperature level is lowered by suppression of the radiator inlet stream temperature in the regenerative heat exchanger by transferring some of its heat to the radiator outlet flow. The flow split between the regenerative heat exchanger and its bypass is established by a temperature control set to 40°F and located downstream of the junction of the bypass and the flow from the regenerative heat exchanger. There is a possibility that under emergency conditions the radiator load may rise above the design value. In this case the bypass will be full open and the temperature level of the entire system will rise to a point where the radiator can reject the heat.

The fluid enters the system at a temperature of 40°F and circulates through the items to be cooled, and then to heaters in the water reclamation system, cryogenics, and hot water cooler. It then enters the radiator via the regenerative heat exchanger. FC-75 was selected as the heat transport fluid because it provides the lowest pumping power to heat transfer ratio and has a very low freezing point.

The coolant leaves the radiator where the stream divides, part going to the regenerative heat exchanger and part bypassing. They then rejoin and mix to a temperature of 40°F. From this point the coolant goes to the cold water cooler to provide the coldest possible water without penalizing the system. The flow then divides again and passes through the main heat exchanger and wash water condenser. These components receive the coldest coolant to maintain an acceptable cabin relative humidity without requiring excessive air flow, and to provide the minimum wash water system penalty. During suit operation the wash system will not be operating and the entire flow will be diverted to the main heat exchanger. The flow leaves these components and rejoins, passing through the cabin cooler. In the event that the cabin is unpressurized and the men are on suit operation, all of the flow must be sent to the suit heat exchanger to remove the load contributed by the suit fans and CO_2 removal system.

The flow leaving the cabin cooler and suit heat exchanger then passes through a diverter valve which divides the flow such that the electronics outlet temperature is maintained at 120°F. This is to assure the proper temperature fluid for the wash and urine water reclamation systems. The control is set to provide at least some minimum flow through the electronics to prevent hot spots. If the variable electronics flow proves unacceptable, a resistance heater could be installed downstream of the

6.2.4 (Continued)

electronics which would utilize power not drawn by the electronics. This would be necessary only when large blocks of electronics are turned off.

The coolant divides after leaving the electronics to go to the wash water air heaters, urine air heater, and potable water storage tanks. From here, it goes to the cryogenic heat exchangers, rejoins with the electronics bypass, passes through the pumps, and returns to the regenerative heat exchanger and radiator.

The only requirement of heat at a temperature higher than 120°F in the system is the hot water storage tank. As this is a small requirement, it was not considered practical to utilize waste heat with its reliability and integration problems. Further, electrical heat proved too severe a penalty. As a result, an isotope heat source will be installed in the tank and excess heat will be removed by the heat transport loop.

The method of heat rejection selected for the Mission Module is a space radiator. The selected radiator for this module was dictated by the load to be dissipated and the area available on the spacecraft. Studies were performed to determine the optimum tube spacing and method of meteoroid protection to result in the minimum weight radiator which could be made to fit within the area available. The resulting radiator requires 16 tubes which are 31 feet long and spaced at a distance of 14.6 inches. Two basic types of meteoroid protection were studied for this radiator. The first is the heavy tube protection which was evaluated using the Bjork penetration criteria and the multi-sheet protection which is evaluated using the Charter's-Summer's penetration criteria. The reliability can be increased considerably by using several extra tubes, with valves to isolate a panel in the event of a puncture. By using the extra panel and multi-sheet meteoroid protection, a no puncture probability of better than .9999 can be attained for a total weight of about 100 pounds. Therefore, the radiator selected has 18 tubes (2 more than minimum required) divided into 9 panels of 2 tubes each, 31 feet long and 14.6 inches apart.

6.2.5 Weight and Power Summary

Table 6-2 presents a weight and power summary of the various subsystems included in the MMM Environmental Control and Life Support System (EC/LSS).

TABLE 6-2

MMM - EC/LSS - SYSTEM B

WEIGHT AND POWER SUMMARY

Subsystem	Average Power Watts	Dry Weight Lbs.	Fluid and Expendable Weight Lbs.	Total Equivalent Weight Lbs.
Ventilation	388	248.1	70.7	512.8
Heat Transport Fluid	75	38.9	120.0	196.4
CO_2 Management	1,030	267.3	145.0	927.3
Water Management	69	164.3	539.0	737.4
Atmospheric Supply		317.7	1,741.0	2,058.7
Miscellaneous*		376.8		376.8
Space Radiator		63.0		63.0
Spares		371.4		373.0
System Total	1,562	1,847.5	2,615.7	5,245.4

* Includes Control Panel, Hygiene Equipment, Feces Processor, Ducting, Clamps, Brackets and Mounting.

6.3 Mars Excursion Module

6.3.1 General

This section presents a summary of the work on Mars Excursion Module System Integration. The discussion will be presented in four sections according to the various functional areas. These are: 1) Air Circulation Loop, 2) Liquid Transport Loop, 3) Thermal Control Loop, 4) Air Lock Operation. This section is a summary and therefore will not present the details of this system. More detail can be found under Section 4.0 of Volume 3 of this Report.

In addition to the usual criteria for selection of systems (weight, power and reliability) there are some unique features of the operational conditions of this module that are significant to this section. These are:

a) During operation on the Mars surface there will be a gravity field. This will simplify some systems such as waste collection and liquid transfer.

b) There will be an initial hold period of 120 days before the systems are operated.

c) All possible weights will remain behind on the Mars surface when the mission is completed.

The power supply is another spacecraft system which was very influential in the selection of the environmental control and life support system approach. Although the power supply selection was not the responsibility of this study, the choice of a fuel cell affected the carbon dioxide management system and the water management system. It is planned to utilize the cryogenic fluid, which supplies the fuel cell, as the freezing medium for a cryogenic freeze-out CO_2 removal system, and to utilize the water produced by the fuel cell for both drinking and washing purposes.

6.3.2 Cabin Atmosphere Circuit

The cabin atmosphere circuit can be more easily understood if the reader will refer to the simplified MEM Schematic, Figure 6-9 and the Cabin Atmosphere Flow Chart, Figure 6-10. The primary loop provides the humidity and contaminant control. Airflow from the cabin enters first through a debris drap which removes large particles and then through the fans. These fans are redundantly installed although only one would function at a time. This main flow then passes through the charcoal canister to remove contaminants. A chemisorbent canister and catalytic burner are located

6.3.2 (Continued)

as shown in order to utilize the pressure rise of the main fan to induce flow through these components. Next the flow enters the condensing heat exchanger where the metabolically generated water (from respiration and perspiration) is condensed. Following this the flow enters the electrically driven rotary water separator where free moisture is removed and pumped to the water processing subsystem. A portion of the main flow enters the CO_2 removal system at this point where the required pressure rise is provided by an independent fan. This location was chosen for minimum absolute humidity to reduce the load on the silica gel in the CO_2 removal subsystem. Finally, the flow passes through a fine filter that removes minute particles before being returned to the cabin.

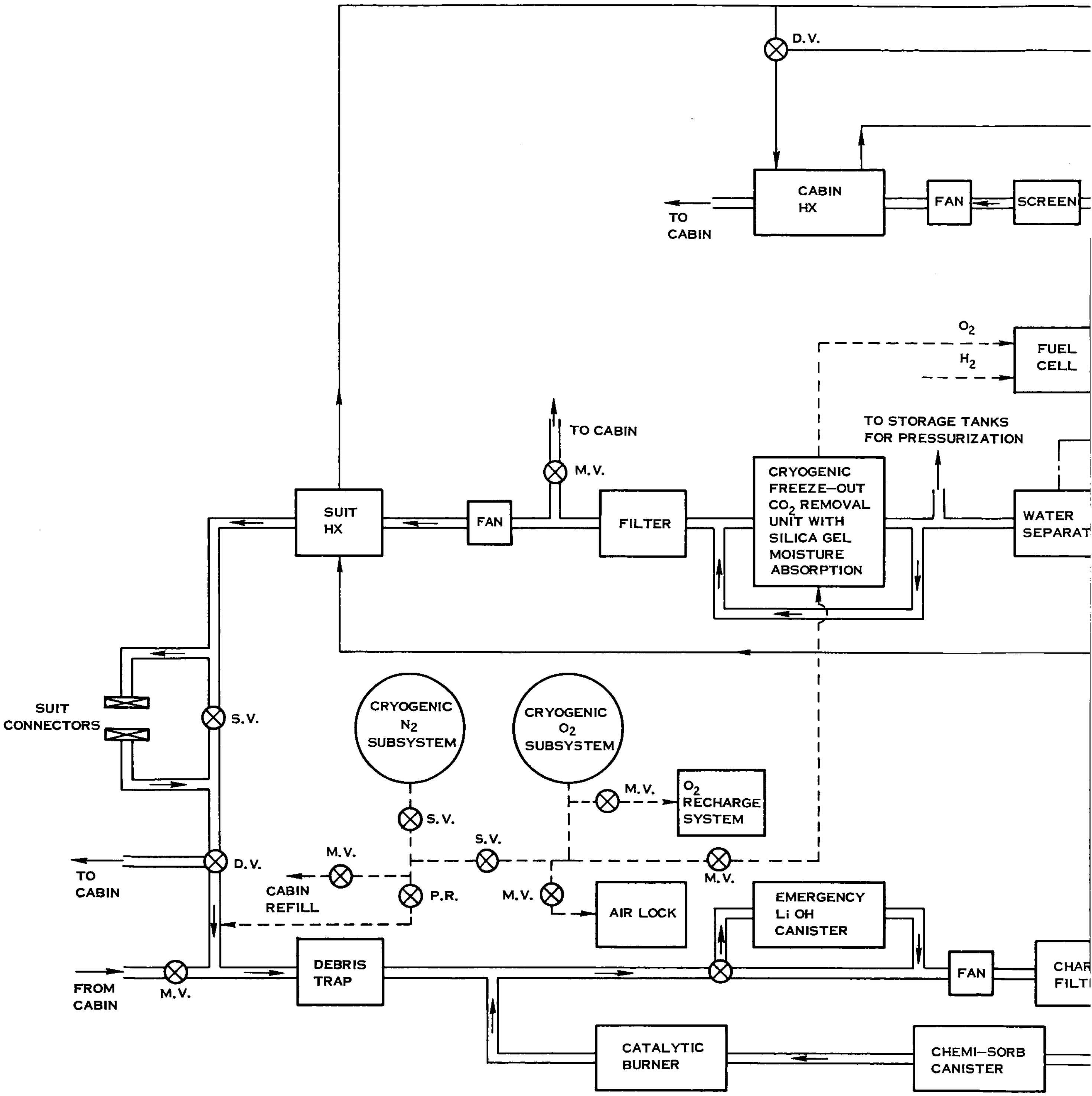
If suit operation is required, a separate fan is turned on as described later under suit operation.

The secondary air loop provides sensible thermal control and air circulation as required for comfort within the cabin. The flow passes through a screen, enters the fans, and is passed through air-to-liquid cabin heat exchanger. The temperature of the liquid entering this heat exchanger is controlled to provide cooling or heating as required. Following this, the flow enters the ducts for distribution throughout the cabin.

This two loop system was chosen to reduce the required fan power. The primary loop is a low flow, high pressure drop system while the secondary loop, with a high flow, has only the low pressure drop of one heat exchanger and screen.

The atmospheric constituents, O_2 and N_2, are stored separately in subcritical cryogenic tanks. Required gas flow is regulated by a total pressure regulator, while a selector valve operated by an oxygen partial pressure sensor determines which gas is supplied. This gas flow is directed into the main recirculation loop just upstream of the debris trap.

A Lithium Hydroxide Canister in the primary loop is suggested as an alternate means of removing CO_2 during the 55 hour return trip from Mars to the orbiting Mission Module. Due to the penalties involved in removing payload from the Mars surface, it may be preferable to leave the cryogenic freeze-out system behind and use the lighter LiOH for the short mission. It is estimated that a suitable LiOH system would weigh only 35 lb in contrast with the launch weight of the cryogenic freeze-out system at 70 lb. The final choice between these two systems will depend on the actual fuel penalties involved in launch from the Mars surface.



MARS EXC
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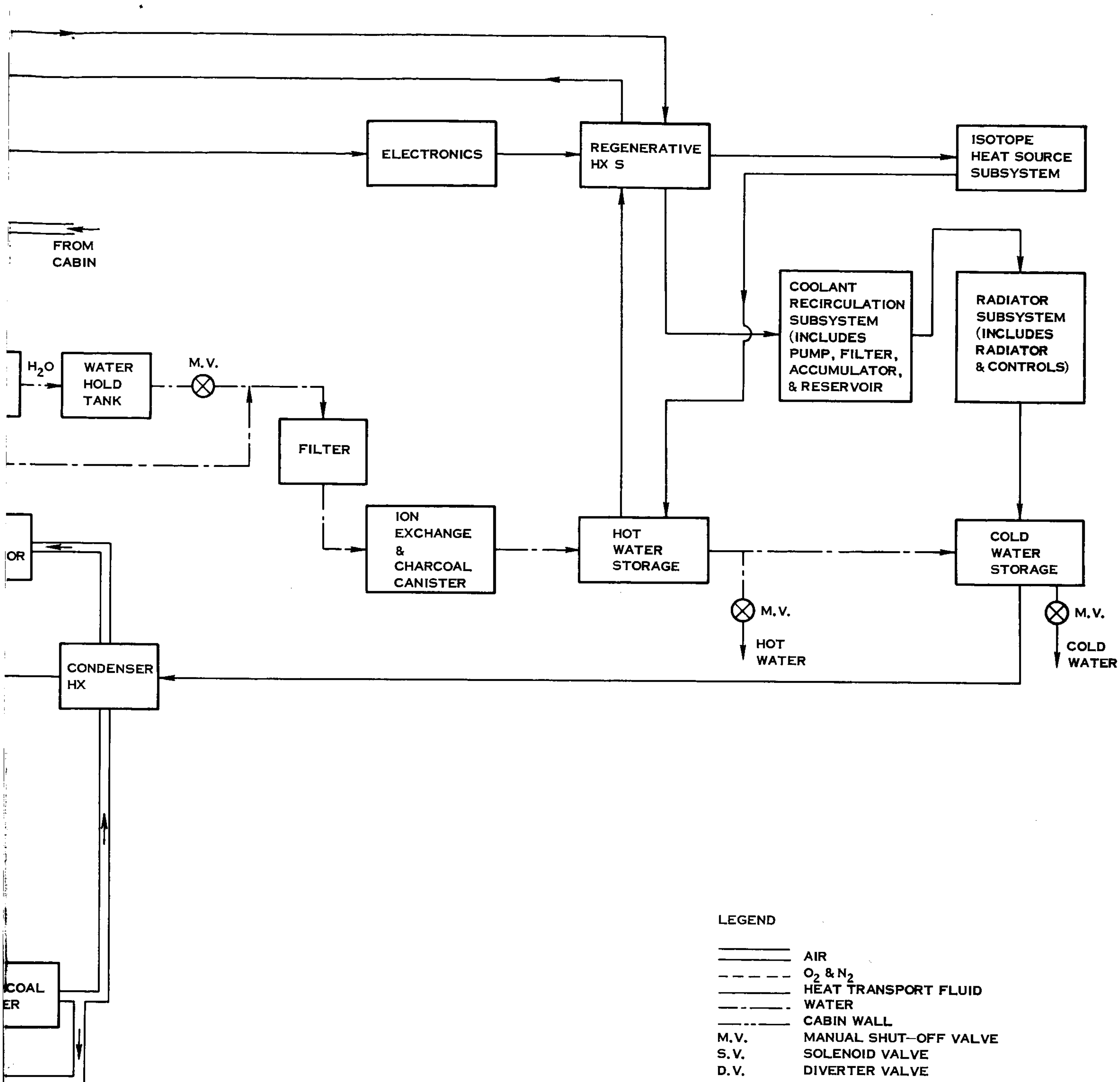
1



CURSION MODULE
ROL AND LIFE SUPPORT SYSTEM
IED SCHEMATIC

URE 6 — 9

#2

MARS EXCURSION MODULE
AIR LOOPS

W = LB/MIN
Q = BTU/MIN
T = °F

CASE I SUMMER, MIDDAY, MAX.HEAT LOAD

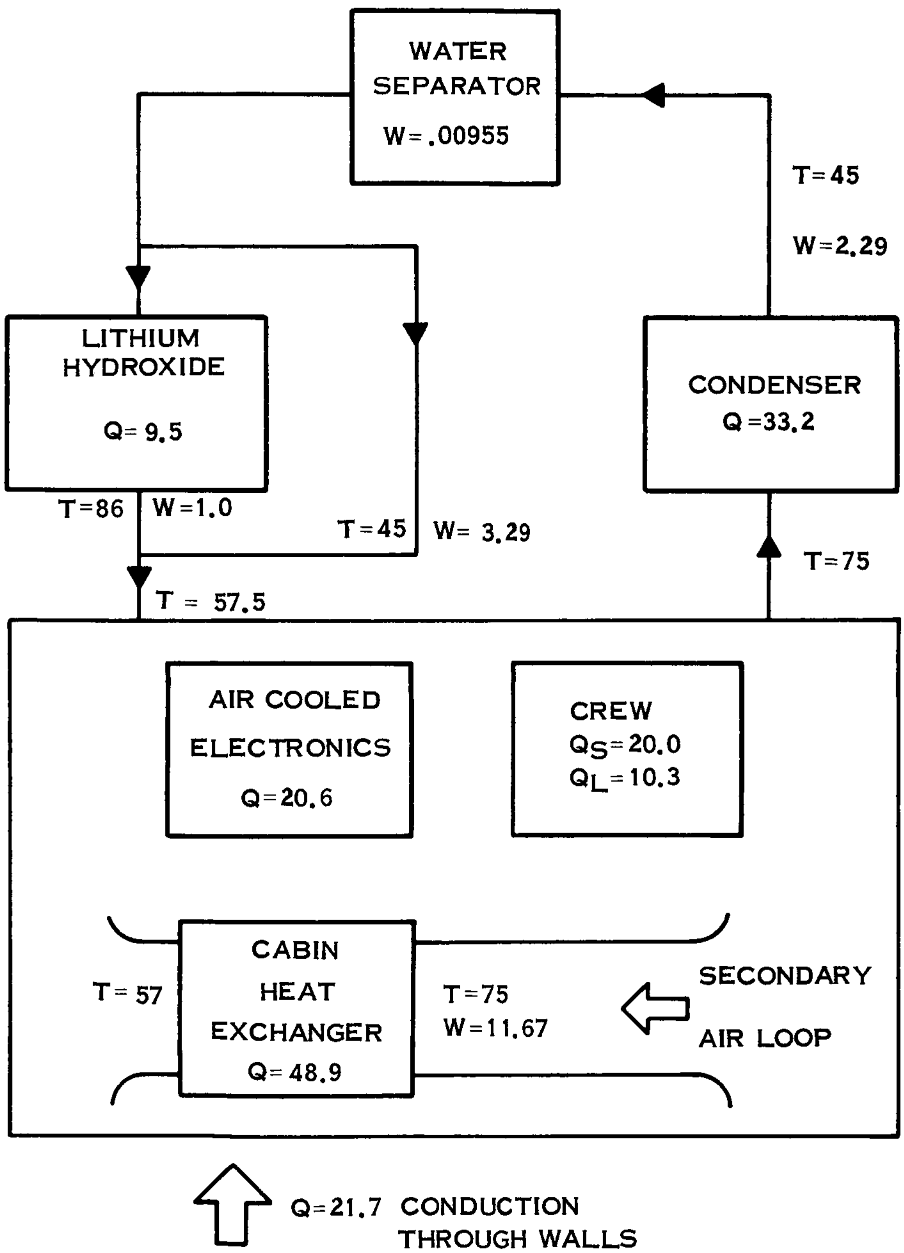


FIGURE 6 — 10

6.3.3 Liquid Loops

The liquid transport loop can be traced with the aid of the system schematic, Figure 6-9 and Heat Transport Loop Flow Chart, Figure 6-11. For the main loop, the coolant chosen was FC-75 in accordance with the survey presented in Volume 2 on heat transport fluids. This coolant leaves the radiator where the temperature is modulated by a regenerative heat exchanger to a temperature of 40°F. This is adequate to provide humidity control, but safely above the freezing point of water.

The flow then passes through the water cooler and enters the primary loop condenser. Here it cools the airstream and removes the latent heat of the respiration and perspiration water. From the condenser, it passes through the suit loop heat exchanger. If the suits are in operation, this heat exchanger is required to remove the suit fan heat load.

The fluid next passes through the cabin heat exchanger in the secondary loop. If cooling is required the flow goes directly to the heat exchanger, but if heating is required the flow first passes through two regenerative heat exchangers where it is heated. This cabin temperature control scheme is significantly different than that for the Mission Module because both heating and cooling are required. This is accomplished by mixing cold fluid from the main and suit heat exchangers with hot fluid that is obtained by passing the supply through two heat exchangers which obtain heat from the high temperature portions of the loop. Thus, the cabin heat exchanger inlet temperature can be controlled by a simple mixing process. The cabin temperature sensor is used to adjust this inlet temperature control set point as a function of cabin temperature.

From the cabin heater the flow goes to the CO_2 removal system where it provides cooling for the silica gel beds and then passes through the electronics section. The electronics are installed on a liquid cooled cold plate so that 90% of the heat load is removed by the liquid loop and only 10% by the cabin air.

This completes the cooling functions to be performed by the liquid transport loop; therefore, the fluid is then heated. Forty percent of the flow enters a regenerative heat exchanger and then flows to the isotope heat exchanger. The isotope loop flow through the heat exchanger is modulated to maintain the FC-75 loop outlet temperature from the heat exchanger at 250°F in order to desorb the silica gel canister in the CO_2 system.

After leaving the CO_2 system, the hot flow passes through the hot water storage tank to maintain the water at 140° to 160°F. This flow is modulated by a bypass valve to prevent boiling of the water in the tank. The flow then passes through two regenerative heat exchangers to rejoin the main flow before entering another regenerative heat exchanger.

MARS EXCURSION MODULE

LIQUID TRANSPORT LOOP (FC-75)

W - LB/MIN
Q - BTU/MIN
T - °F

CASE I SUMMER, MIDDAY, MAX. HEAT LOAD

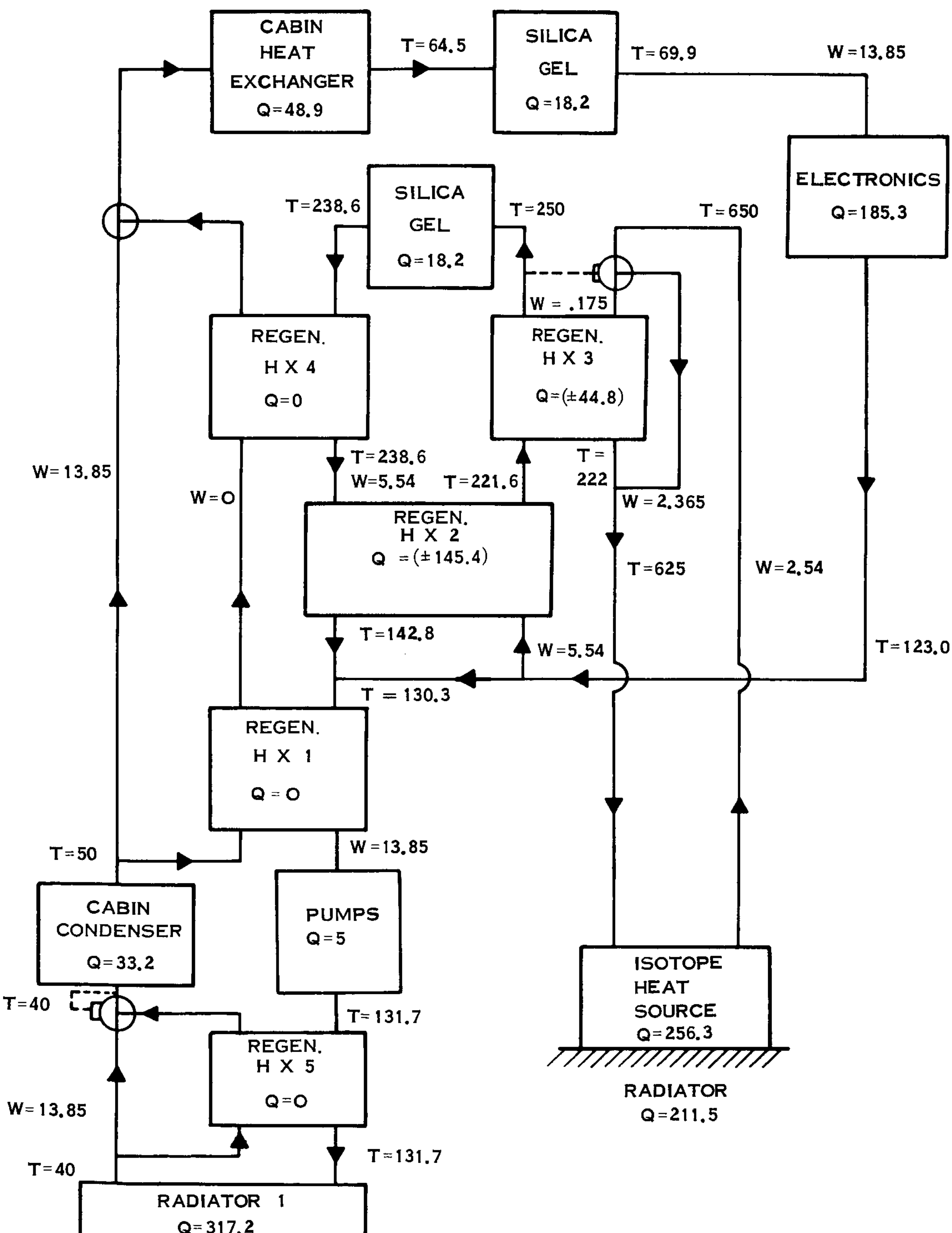


FIGURE 6-11

6.3.3 (Continued)

After this, the flow returns to the pumps, the radiator regenerative heat exchanger, and finally the radiator.

There are two requirements for heating on this module. The silica gel beds in the CO_2 removal system require a small amount of heat, and a large quantity of heat is required for cabin heating under cold day conditions. If the landing site were changed, such that cabin heating was not required, heat could be obtained from the fuel cell. However, because a large quantity of heat is required, a 4.5 KW isotope heat source has been included in the system. This isotope source cannot be modulated but continues to generate heat in proportion to the quantity of radioactive material. Because of this characteristic, care must be taken to avoid dead spots in the flow path within the source as well as to provide uninterrupted heat rejection capability. If the isotope is cooled directly by the main coolant loop, the reliability requirements for this loop are significantly increased. Failure of the coolant flow would cause vaporization of the fluid within the isotope heater. In addition, the chemical stability of the FC-75 is in question at the temperature which might be reached in this case. To provide heat rejection with loss of coolant flow, the heat source must be allowed to radiate to space. Consequently, the heater will be radiating continually and must be oversized to allow maintenance of the design temperature while radiating from an area sized to prevent overheating in a failure condition. Fluid temperature on the order of 800°F during coolant flow failure will be necessary to prevent excessive radiation at the design condition. Assuming that the fluid can withstand these temperatures without breakdown, the coolant accumulator must be sized to accommodate the fluid displaced due to vaporization in the isotope heater. A further requirement is that a condensing heat sink that is not adversely affected by 800°F fluid must be provided to allow start-up following interruption of coolant flow.

Based upon properties of presently available fluids, the temperatures associated with coolant flow failure are not acceptable to the main coolant loop and must be avoided. To do this without imposing extremely high flow reliability requirements, a separate loop using a high temperature fluid must be used. The heat can then be delivered to the main loop through a heat exchanger around which the high temperature fluid is bypassed to limit the main fluid loop temperature. Thus, the isotope heat source is free to seek its own equilibrium temperature while the main coolant temperature range is not violated. The controller for this system will be a direct acting mechanical bypass control like that described for the waste heat temperature control on the MMM.

6.3.4 Thermal Control

The final element in the environmental control system is the thermal control and space radiator system that rejects the vehicle heat. During maximum load operation the main radiator must reject 317.2 BTU/min. at a temperature level that will provide coolant at 40°F outlet temperature for humidity control. On the other hand, during minimum load operation the problem of radiator freezing must be avoided. The freezing temperature of FC-75 has not been defined, but it is definitely below -65°F. Therefore, it was decided to maintain the radiator outlet temperature above -65°F at all times.

The second radiator, for the isotope waste heat source, is required to dissipate heat during the 120 day mission from the Earth to Mars, since the isotope source generates heat continuously once activated.

The main radiator heat load was determined from the system heat loads and is specified on the flow chart, Figure 6-11. The 40°F outlet temperature has been chosen as the minimum practical temperature to achieve humidity control while still avoiding freezing of condensed atmospheric water. A higher liquid outlet temperature would ease the radiator design problem, but preliminary estimates have indicated that the weight saving would only be about one pound per degree increase in radiator outlet temperature.

In order to optimize the installation and eliminate the fin weight, the radiator has been incorporated into the vehicle skin. A further reason for employing an integral radiator rather than a separate one deployed on the Mars surface is that heat dissipation from the radiator will be required during the 55 hour rendezvous mission. The flat upper surface of the vehicle depicted by Aeronutronics Division of Ford Motor Company was selected as the most suitable location for the integral radiator.

A radiator was designed that would meet the specifications outlined. In order to remain within the limited flat area available, a tube spacing of approximately three inches was selected along with a tube length of 20 feet.

The danger of radiator freezing constituted another problem. With very low heat loads during the cold portions of the mission there is danger of the radiator freezing. In order to make the radiator compatible with this condition, it is proposed to fit shutters of "Venetian Blind" type to reduce the heat rejection capability to about one third of its full capacity. The use of lightweight blinds of this type is considered practical since this minimum load condition only occurs while on the Martian surface. With the addition of this system to prevent freezing, it will be possible to reject the minimum load while still maintaining the fluid outlet temperature above -65°F.

6.3.4 (Continued)

In summarizing this section of the discussion, it can be said that a difficult radiator design problem has been presented by the large variation in heat rejection loads combined with the variation in radiator influx. Throughout the system integration study, reliability has been considered, but mostly in qualitative terms. However, for meteoroid protection the armor weight is intimately connected with the probability of avoiding meteoroid puncture. Consequently, quantitative estimates have been made of the system reliability on this basis.

Two different means of protecting the radiators may be used. One is to add heavier walls to the tubes on the side facing the outside of the vehicle, and the other is to provide multiple sheets of protection with spaces between them. The actual meteoroid protection required for a space vehicle is a function of both the meteoroid flux in the region of operation and the duration of the mission. The Excursion Module passes through three different flux regions over a 160 day period.

For this module, a probability of no puncture of .99 can be provided for a radiator weight of about 57 pounds using heavy walled tubes. However, to provide a probability of no puncture of .999 the weight increases to over 150 pounds. This weight can be brought down to about 68 pounds by providing a 10% larger radiator than required with valves to isolate any panel. Therefore, the radiator used in this module is of this latter type.

This study has assumed that the radiators will work satisfactorily on the Martian surface and that the atmosphere is transparent to radiation. This assumption is based upon the model atmosphere defined in the Mars Mission Report dated April 19, 1963, prepared by O. O. Ohlsson. This indicates an almost complete absence of water vapor, and it is water vapor which is responsible for most gas radiation in the Earth's atmosphere. It is not believed that the limited quantity of CO_2 would contribute a significant amount of gas radiation, and on this basis the Mars atmosphere has been assumed transparent.

After more is known about the Mars atmosphere, the effect of CO_2 gas radiation upon radiator performance should be investigated. To study the problem, the Mars atmosphere would be considered to consist of layers with the density decreasing with altitude. These layers would be compared to a mathematical model of a series of perforated plates. Each one of these would have absorption and transmission of radiation appropriate to the local conditions at that altitude. Since the radiation characteristics of CO_2 are a function of wave length and in fact occur largely in discrete narrow bands, this variation would have to be integrated over a series of bands throughout the wave length range of interest. The summation of the effects

6.3.4 (Continued)

of these wave length bands and atmospheric layers would provide an equivalent emissivity for the Mars atmosphere that would be employed in determining overall radiator performance.

The system schematic, Figure 6-9, and the Flow Chart, Figure 6-11, show a separate radiator system for the isotope waste heat source. One problem that presents itself in integrating an isotope heat source is that it generates heat continuously once activated. This means that the full heat load of this source must be dissipated during the 120 day journey to Mars. Since the MEM vehicle will be uninhabited during this time, it is important that the heat dissipation system be reliable and independent of maintenance. For this reason the choice was made for a "passive" system that could function without coolant pumps.

The isotope source will be installed in the vehicle so as to have intimate thermal contact with the vehicle skin. The skin in this area will be covered with a radiator coating. The coolant passages carrying the Dowtherm A are located on the inside of the isotope source and conduct the heat away as required. During the Earth to Mars journey, the fluid will not be pumped and the system will simply run hot enough (700°F) for the skin to dissipate the entire heat load.

6.3.5 Air Lock Operation

The operation of the vehicle airlock is fundamental to the Mars exploration missions since the astronauts enter and leave through the airlock for their exploratory trips. It is assumed that two astronauts will each make fifty trips, one a day for forty days plus ten airlock operations for contingencies.

The operation of the airlock presents two problems for the MEM Environmental Control System. First, there is the loss of cabin atmosphere with each airlock operation. With 150 operations of a 42.5 cubic ft. airlock, the total loss of atmosphere can be as high as 236 lb. and consequently will significantly increase the weight of the atmospheric storage subsystem. Secondly, there is the problem of entrainment of Martian atmosphere each time the airlock is operated. According to the current specifications, this atmosphere will consist primarily of nitrogen with traces of CO_2 and Argon. Consequently, this will not provide any serious problem for the crew or the operation of the environmental control system.

However, the nature of the Mars atmosphere is uncertain and if future evidence should indicate it to contain toxic gases, the operation of the airlock would result in a contaminant control problem. This study was therefore limited to an examination of loss of cabin atmosphere only, due to the lack of information on the toxicity of the Martian atmosphere.

6.3.5 (Continued)

Several means have been considered for minimizing the loss of atmosphere from the airlock. The first of these is the use of an airlock pump. In this system the airlock atmosphere is pumped back into the main cabin before the astronaut leaves the chamber. The amount of atmosphere saved is directly proportional to the pump-down pressure. If no pumping is carried out, the maximum loss will occur. This amounts to a total weight of 281 lb based on subcritical storage. If the airlock is pumped down before opening the exit door, the loss of atmosphere will be reduced. This study has indicated that pumping down to Martian atmospheric pressure (1.26 psia) in a one minute time period will cost only 23 pounds for the pumping equipment and 50 pounds for the lost atmosphere. This total weight of 73 pounds is a saving of 208 pounds over a simple airlock concept. These weights assume that 1.2 KW of equipment can be turned off each time the airlock is operated, so it is not necessary to charge the system with the 150 pounds per kilowatt penalty for using the fuel cell.

Several other methods of decreasing the penalty for lost atmosphere which were considered are listed below with the associated weight penalties along with the methods discussed above for comparison.

Airlock	Operation	Equivalent Weight
(a) Simple single airlock	Two astronauts out together	281 lb for atmosphere lost
(b) Single lock with Lysholm compressor	Two astronauts out together	73 lb for atmosphere lost plus pump and motor
(c) Single lock with contoured inserts	Two astronauts out together	49.5 lb for atmosphere lost plus additional structural weight for contoured airlock
(d) Simple single lock	Two astronauts out separately	187 lb for atmosphere lost
(e) Double lock	Two astronauts out together	140 lb for atmosphere lost plus additional structural weight for second lock

It can be seen from this table that the two methods which result in the greatest weight saving are pump down and the contoured lock. Since there is no experience with contoured airlocks, the pumpdown method is suggested for consideration at this time. However, it is recommended that additional future study be devoted to the contoured airlock.

6.3.5 (Continued)

The contoured airlock consists of a pair of clamshell doors filled with a molded plastic insert. The insert has the form of the astronaut molded into it with about a 3 inch clearance all around. By this means the effective volume of the airlock is greatly reduced. More detail on this airlock can be found in Section 4.2.2.7 of Volume 3 of this Report.

With a simple single airlock used, 281 lbs. of atmosphere are lost if two astronauts go out together, whereas only 187 lbs. of atmosphere are lost if two astronauts go out separately. This 3 to 2 weight ratio is due to the fact that, with two astronauts going out together and returning, 3 airlock dumps are required, but when two astronauts go out separately (i.e., one goes out and returns, then the other goes out and returns), only two airlock dumps are required.

In the first situation one astronaut enters the filled airlock then leaves when it is dumped (first dump). The airlock is then refilled and the second astronaut enters. The airlock then dumps for the second time and the second astronaut leaves the airlock. Upon returning from the trip, one astronaut enters the airlock which is then filled so that he may enter the Excursion Module cabin. The airlock is now dumped for the third time so that the other astronaut may enter it. The airlock is then filled and the second astronaut enters the Excursion Module cabin.

When the astronauts go out separately, one astronaut enters the filled airlock which is then dumped. He leaves the airlock, completes his trip, and enters the airlock which is then refilled. When he enters the Excursion Module cabin the airlock is ready for the use of the second astronaut who also will utilize only one dump for his exit from and return to the Excursion Module.

6.3.6 Weight and Power Summary

Table 6-3 presents a weight and power summary of the various subsystems included in the MMM Environmental Control and Life Support System (EC/LSS).

TABLE 6-3

MEM - EC/LSS

WEIGHT AND POWER SUMMARY

Subsystem	Average Power Watts	Dry Weight Lbs.	Fluid and Expendable Weight Lbs.	Total Equivalent Weight Lbs.
Ventilation	497.5	173.5	5	969.5
Heat Transport Fluid	75.0	121.5	100	340.8
CO_2 Removal	25.7	112.4		153.3
Water Management	10.0	16.8	30	46.8
Atmospheric Supply		138.4	543	760.3
Miscellaneous *		154.0		154.0
Space Radiator		158.0		158.0
Isotope Heater		100.0		100.0
Spares		130.9		130.9
System Total	608.2	1,105.5	678	2,813.6

* Includes Control Panel, Hygiene Equipment, Feces Processor, Ducting, Pipes, Brackets, and Clamps.

6.4 Earth Re-entry Module

6.4.1 General

This section summarizes the selection of subsystems and operation of the Earth Re-entry Module system. This section is intended as a summary only. Additional detail may be found in Section 5.0 of Volume 3 of this Report.

The Earth Re-entry Module is utilized for two relatively short periods of time separated by a period of 420 days. It is used to transport the crew from Earth to the orbiting Mission Module prior to the trip to Mars, and is used to return the astronauts to Earth on their return from Mars. The first operational period is 12 hours and the second is 3 days. Due to the short operating time, it is generally advantageous to use simple, non-regenerative type subsystems. The operation of the ERM system will be broken into two functional areas for the discussion of its operation. These will be the cabin atmosphere loop, and the heat transport loop.

6.4.2 Cabin Atmosphere Loop

The cabin atmosphere loop is shown in the simplified ERM system schematic, Figure 6-12, and the Flow Chart, Figure 6-13. The design point was selected to provide adequate environmental control and atmosphere control for a crew of six while in shirt sleeves or space suits.

The cabin atmosphere loop consists of two separate sub-loops. A flow sufficient to provide contaminant and humidity control is circulated through the humidity and contaminant control loop, and the remaining flow, required to provide sensible cooling to the cabin, is circulated through the low pressure drop cabin circuit.

The humidity and contaminant control loop contains a debris trap for removal of free moisture and solid particles, a LiOH canister for CO_2 removal, and a chemisorbent bed and catalytic burner for removal of other contaminants. In addition to these and the circulating fans, there is a condensing heat exchanger and water separator for humidity control and a suit heater to provide higher dry bulb temperatures if required under suit operation conditions.

The cabin cooling circuit consists simply of a fan and cooling heat exchanger. The temperature of the discharge air coming from this heat exchanger is kept above the dew point to prevent condensation in this circuit when atmospheric supply to suits is uncomfortably cool.

The atmosphere in this module is a nitrogen and oxygen mixture as in the other two modules of the Mars vehicle. The nitrogen for leakage make-up and the oxygen for leakage make-up and metabolic use are both stored in the gaseous state, and are

6.4.2 supplied to the cabin or suit circuit as required by a demand regulator and selector valves. The selector valves are controlled by an oxygen partial pressure sensor.

6.4.3 Heat Transport Loop

The heat transport fluid loop connects the various components in the system providing heating or cooling as required, and ultimately carrying the excess heat to one of the various heat sinks for rejection overboard. The discussion of this loop will begin at the point where the heat transport fluid leaves the heat sink, will describe the functions performed throughout the loop, and will end at the heat sink. The fluid chosen for use in this loop if FC-75.

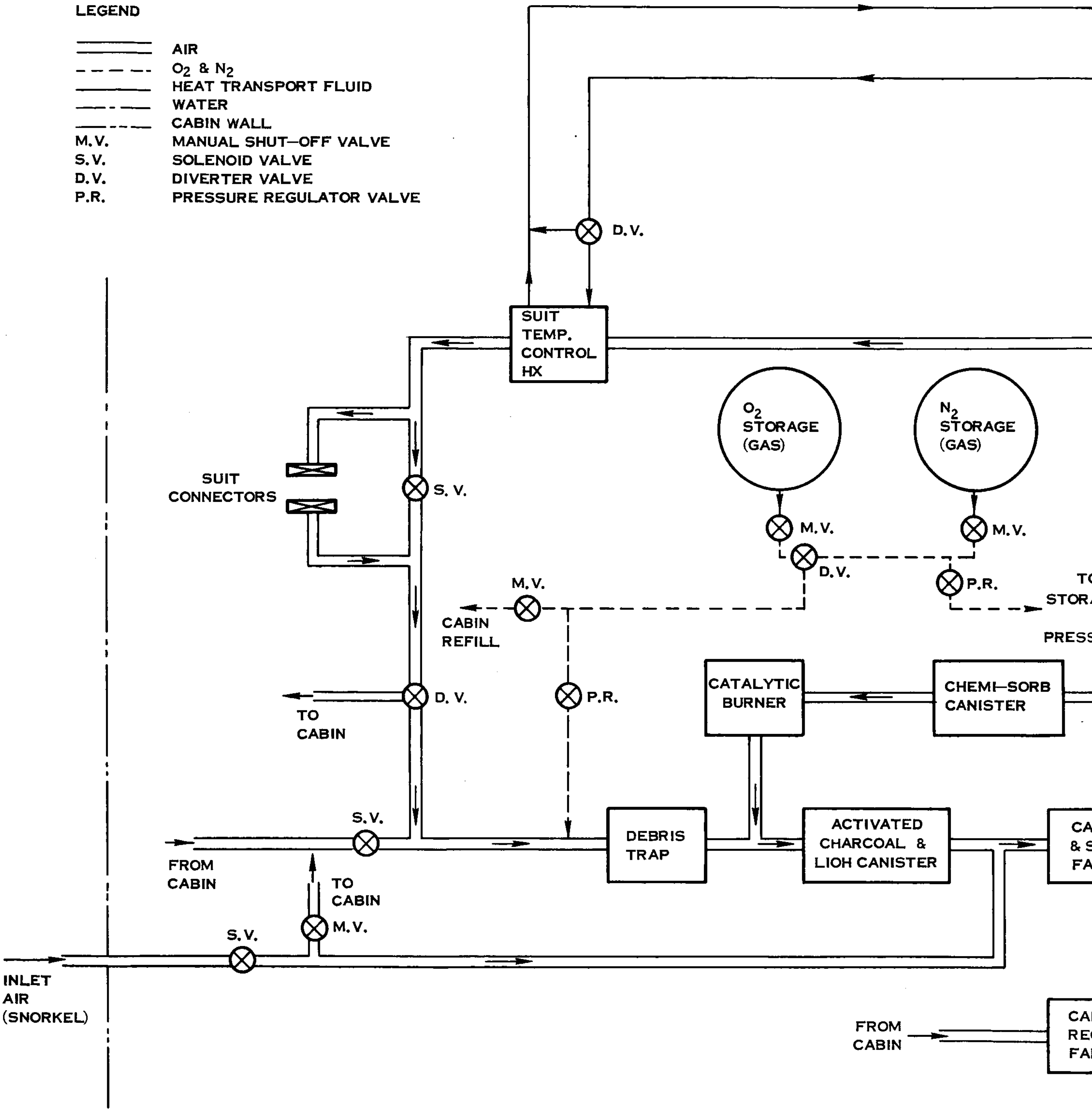
This module has severe heat rejection requirements since it goes through four different modes of operation. The first mode of operation is Earth launch to rendezvous with the Mission Module,and lasts about twelve hours. The second mode is the pre-re-entry and checkout phase, which begins when the crew enters the module to check it out, and ends when the module begins to enter the Earth's atmosphere. The third mode is the re-entry phase, which starts when the vehicle begins to enter the Earth's atmosphere, and ends at an altitude of about 100,000 feet. The final mode is the landing and post-landing phase, from 100,000 feet altitude to the time when the crew leaves the module.

The methods of cooling which have been selected for each mode of operation are:

1. First Mode	Water Boiler
2. Second Mode	Space Radiator
3. Third Mode	Water Boiler
4. Fourth Mode	Freon Evaporator

This discussion will consider only the second, or major mode of operation.

The FC-75 fluid leaving the radiator is controlled to a minimum temperature of 40°F by a regenerative heat exchanger and bypass valve in the same manner as the other two modes. From this point the fluid flows to the humidity control and suit loop heat exchanger. At this point the coolant is at its coldest, and the maximum moisture can be removed from the air stream per unit of flow. This will maintain the cabin relative humidity at the lowest possible level for the selected flow rate. The flow then goes to the cabin heat exchanger which does the bulk of the sensible cooling for the vehicle. From the cabin cooler the FC-75 flows through the pumps and then the cold plates for electronics cooling. At this point the coolant is at its highest temperature and is directed to the suit heater, where the hot FC-75 is used to warm the suit inlet air flow if the astronauts are uncomfortably cool. The fluid then flows to the heat sink where it is cooled down to 40°F again.



EARTH RE—ENT
ENVIRONMENTAL CONTROL AND
SIMPLIFIED S

FIGURE

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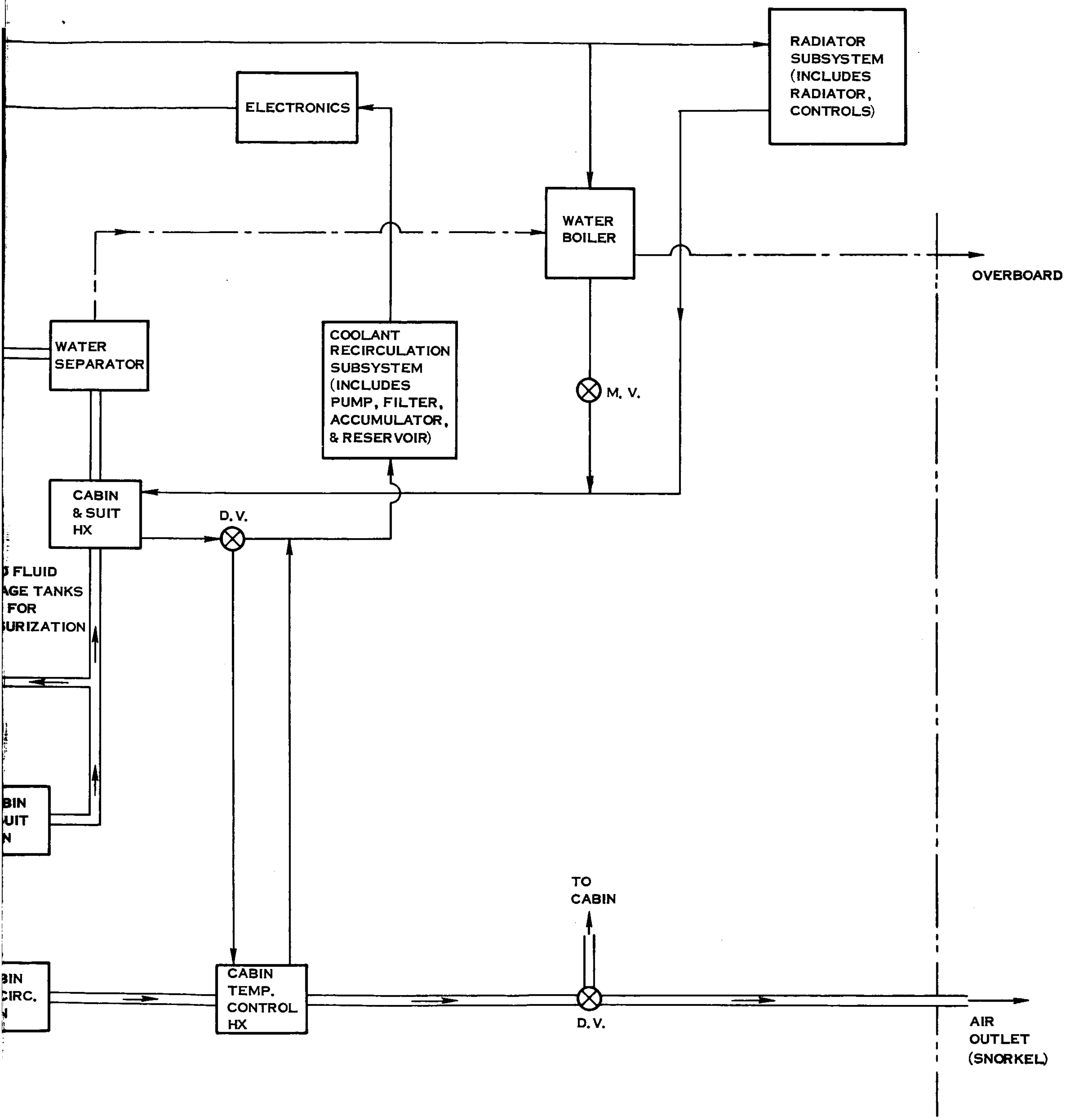

'RY MODULE
LIFE SUPPORT SYSTEM
CHEMATIC

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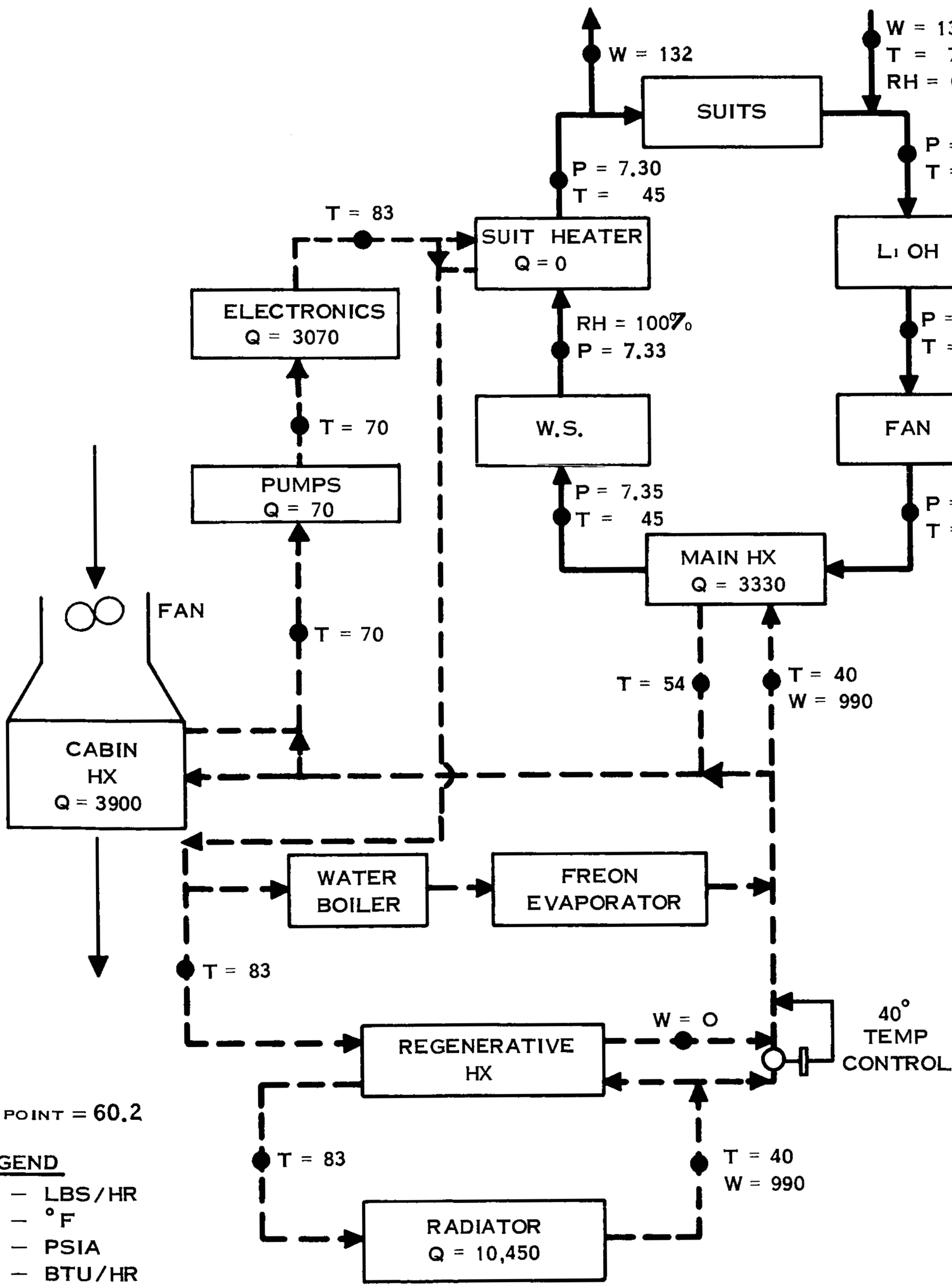
#2

EARTH RE–ENTRY MODULE
DESIGN POINT FLOW CHART



T DEW POINT = 60.2

LEGEND
W — LBS/HR
T — °F
P — PSIA
Q — BTU/HR

FIGURE 6–13

6.4.4 Weight and Power Summary

Table 6-4 presents a weight and power summary of the various subsystems included in the ERM Environmental Control and Life Support System (EC/LSS).

TABLE 6-4

ERM - EC/LSS

WEIGHT AND POWER SUMMARY

Subsystem	Average Power Watts	Dry Weight Lbs.	Fluid And Expendable Weight Lbs.	Total Equivalent Weight Lbs.
Ventilation	318	317.5		822.5
Heat Transport Fluid	75	23.4	39.0	180.4
Water Management		75.0	388.0	463.0
Atmospheric Supply		128.5	80.9	209.4
Miscellaneous*		83.9		83.9
Space Radiator		61.0		61.0
System Total	393	689.3	507.9	1,820.2

* Includes Control Panel, Ducting, Pipes, Clamps, Bolts, Brackets and Personal Hygiene Equipment.